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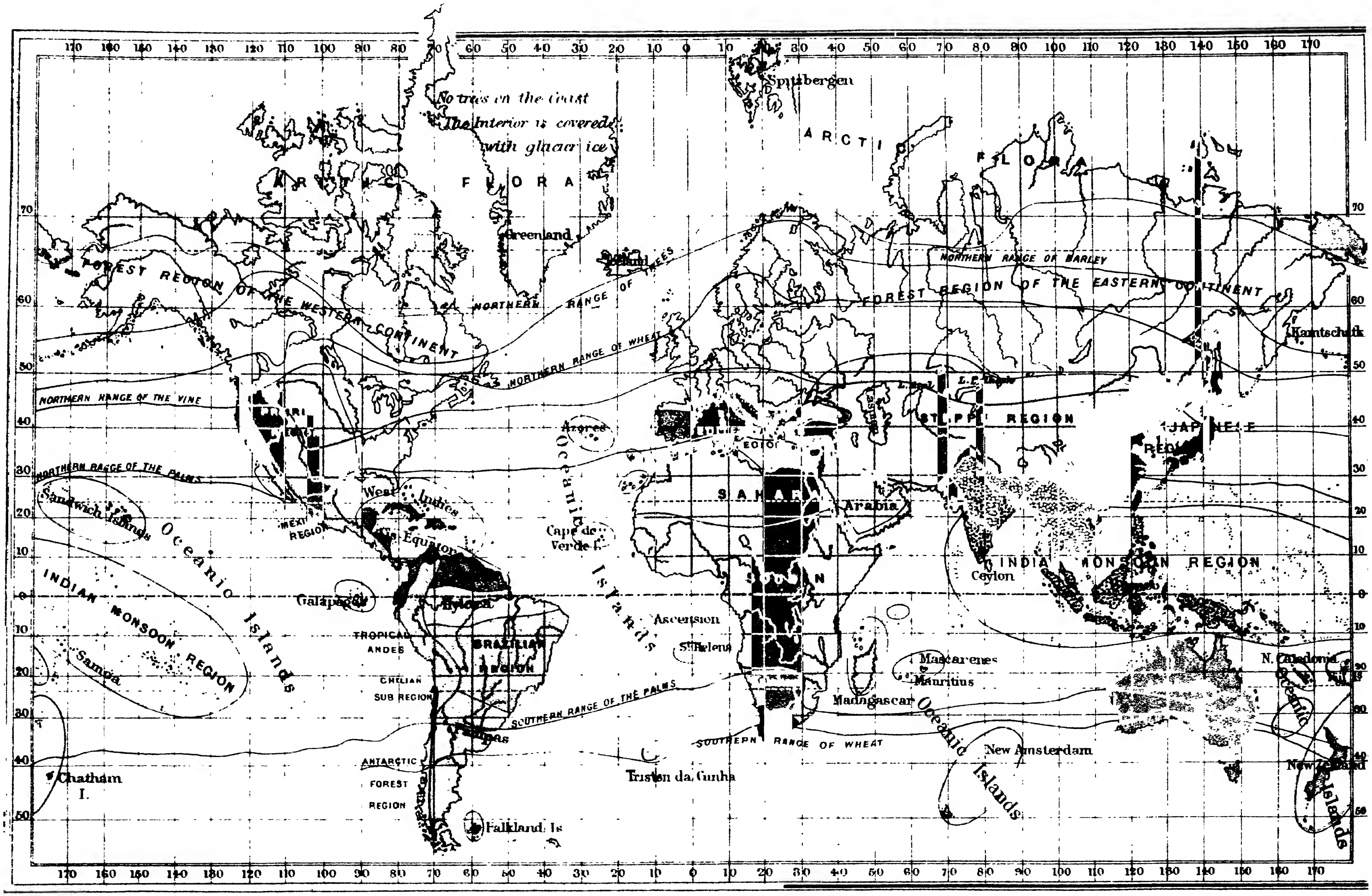
No trees on the Coast
The Interior is covered with glacier ice
Spitzbergen
ARCTIC FLORA
Greenland
Iceland
FOREST REGION OF THE WESTERN CONTINENT
FOREST REGION OF THE EASTERN CONTINENT
NORTHERN RANGE OF BARLEY
NORTHERN RANGE OF TREES
NORTHERN RANGE OF WHEAT
NORTHERN RANGE OF THE VINE
NORTHERN RANGE OF THE PALMS
Kamtschatk
STEPPE REGION
JAPANESE REGION
Azores
Oceanic Islands
SAHARA
Arabia
SOUDAN
West Indies
MEXICAN REGION
Equator
Sandwich Islands
Cape de Verde I.
INDIA MONSOON REGION
Ceylon
INDIAN MONSOON REGION
Galapagos
Hylaea
TROPICAL ANDES
BRAZILIAN REGION
CHILIAN SUB REGION
Ascension
St. Helena
Mascarenes
Mauritius
Madagascar
Samoa
N. Caledonia
Fiji
SOUTHERN RANGE OF THE PALMS
SOUTHERN RANGE OF WHEAT
Pampas
New Amsterdam
New Zealand
Chatham I.
ANTARCTIC FOREST REGION
Tristan da Cunha
Falkland Is
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

MAP ILLUSTRATING THE DISTRIBUTION OF PLANTS OVER THE EARTH

SCIENCE FOR ALL.

EDITED BY

ROBERT BROWN, M.A., PH.D., F.L.S., F.R.G.S.

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Fig. 1.—*Victoria Regia* ON A RIVER IN GUIANA.

HOW PLANTS WERE DISTRIBUTED OVER THE EARTH.

BY DR. ROBERT BROWN, F.L.S., F.R.G.S., ETC.

IT is scarcely necessary to be either a traveller or a botanist to know that different parts of the world produce dissimilar plants. The flowers of the fields of France are many of them different from those familiar to us in England, and the vegetation which clothes the shores of the Mediterranean is widely unlike the scanty herbage which backs the sandy dunes along the coast of the Zuider Zee. Africa again presents an entirely different assemblage of plants from either region; and those of the two sides of that continent present striking differences, both from each other and from those which cover the American tropics. Finally, if the voyager extended his observations to Australia, he would find that in the Antipodes there is scarcely a native plant the same as in Europe. How is this? We have been so accustomed to regard it as the normal condition of affairs, that at first sight we are apt to consider that there must be some notoriously self-evident cause to account for this distribution of plants, which, it may be remarked, is not always coincident with that of animals. It may be said that climate limits the range of plants, and that two countries enjoying the same degrees of heat, and moistened by much the same rainfall, will produce an identical vegetation. This may be true as regards cultivated crops; but it is at once met by the fact that many parts of the world having exactly the same climate are characterised by totally different indigenous plants. For example, why has equinoctial Africa no laurels? and why, with the exception of a few patches in Newfoundland and the neighbouring region, is America devoid of heather? We equally fail to explain why the birds of India glow with colours less splendid than those of the hot parts of America, or why they are different as to species, or why the tiger is peculiar to Asia, and the ornithorhynchus to Australia. It may be allowed that, owing to some peculiarity in their structure, palms and bananas should belong to warm regions—though this is really no explanation of the fact—but we cannot understand how on the climatic theory melastomas do not vegetate north of the 30th parallel of latitude, or why no rose-tree belongs to the southern hemisphere. If climate would account for the distribution of plants, there should be really no reason for the plants of the Cape of Good Hope not being identical with those of Spain or Australia, or for the trees of Oregon being different from those of Ireland.

Nevertheless, though temperature will not altogether, or even partially, explain the present distribution of plants, it has undoubtedly a powerful influence in restraining species within certain limits. Certain grains (see Frontispiece) and other economic species will, for example, grow to perfection only within certain limits, and beyond a certain northern or southern range will either not ripen or die altogether.* Accordingly, it is necessary to say a few words in regard to the influence of climate. Every plant must have a certain degree of heat—greater or less—before it can produce its flowers and fruit. The "zero" of life in different plants is very different, and in general terms may be said to be sooner reached in plants of warm than in those of cold or Alpine countries—each plant being "a kind of thermometer which has its own zero." Moisture is also essential to the life and spread of a plant, for water is required as food, and as a vehicle for the soluble materials on which the plant subsists. It keeps the earth moist, and, indeed, in the case of some aquatic species, it stands in the place of the soil to them. It determines the polar limits of those plants with which the wet climate of the north disagrees, and the equatorial limits of others which require moisture for their growth. Heat, if combined with moisture, modifies in some degree the effects of moisture *per se*. Soil has also, not unnaturally, a powerful influence on plants. Every plant requires a different kind of food, and some plants will not prosper unless they grow in the soil which yields the substances they particularly affect. For instance, the various species of *Carex*, or sedge, and the bent grass—which have the specific term "arenaria" affixed to their name—by this word indicate their taste for a soil notoriously disliked by most plants, namely, sand. The horse-tail (*Equisetum*) grows in marshy places where silica abounds; in Scotland and Ireland the broom rape (*Orobanche rubra*) grows chiefly in districts where decaying traps abounds; while *Erica vagans*, a local species of heath, is in Cornwall almost confined to soil formed of broken-down serpentine. Again, there are plants which love clay soils, others which affect chalky ones, and so forth. In other cases, the limit of a plant is coincident with a particular formation. In California, for example, the redwood (*Sequoia sempervirens*), a gigantic forest tree, grows only on metamorphic slates; and in Mexico the appearance of the great cactus is simultaneous with the change from sedimentary to volcanic formations. These cases are, however, not very common; though it may be said, in general terms, that most plants grow to greater perfection in one soil than in another, and it is the duty of the agriculturist to study this liking, and suit the plant to the land on which it is to be grown. Dr. Schleiden has noticed that the beautiful orchid known as the ladies' slipper (*Cypripedium*) grows over all parts of the Swiss Fore Alps, where the soil is formed of the Alpine limestone. "It accompanies the whole Swabian muschelkalk, and disappears suddenly when we come to the sands of the Jura and Keuper formations on this side the Danube. It next makes its appearance on the muschelkalk of Thuringia, and comes down with that on the Werra, as far as the neighbourhood of Göttingen, and then leaps over the Bunter Sandstein of the Lower Eichsfeld, the granite of the Upper Harz, and again gladdens the eye of the wanderer on the calcareous formations eastward of the Brocken. It is sought in vain all over the clay and sandstone formations of the Northern German plains, till in the extreme north it again shows itself at Rügen, where the chalks of Arcona and Stubbenkammer lift their heads. On the western coast of France grow various insignificant-looking shore plants, species of *Salsola* and *Salicornia*, which the inhabitants there use to obtain soda from the ashes. When we travel from thence towards the East, we everywhere miss these little plants, even when searching most carefully, and one or other of them makes its appearance only in those places where the soil is moistened by some salt spring. At last we arrive at the great Steppes of the south-east of Russia, which in summer are often covered with a thick crust of salt, showing them to be the ancient bottom of some dried-up sea, and here these plants are found growing with the same abundance and luxuriance as in the west of France. On the northern coast of Germany the little pale-red maiden pink grows upon the arid sand dunes, and is universally distributed over the sandy plains of Northern Germany; but these are succeeded by the granite, clay, slate, and gypsum of the Harz, the porphyry and muschelkalk of Thuringia, and our little pink is not met with again till we arrive at the Keuper sand-plains on the farther side of the Maine, surrounding the venerable city of Nuremberg. It extends north through the Palatinate, till the muschelkalk of the Swabian Alps again sets a limit to it; but it leaps over these and the whole Alpine region, and at last appears on the sandy soil of Northern Italy. How is it that these plants everywhere disdain the richest soils in their range of geographical distribution, and are confined to perfectly determinate geognostic formations?"

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* In this map the ranges given for economic plants are merely approximate. It must not be supposed, for example, that wheat will not grow beyond the northern and southern limits marked. Only within these ranges, however, does it prove a profitable crop; in other words, the lines drawn on the map mark the northern and southern limits, up to which any particular crop attains its maximum of development. Outside these lines it either does not ripen, or its ripening is so precarious as to exclude it from the operations of the agriculturist.

Light has also a marked influence on the distribution of plants, though it is not easy to separate it from that of heat. But in studying the agents which limit or aid the spread of vegetable forms, we come to a cause or series of causes more important even than those to which we have briefly alluded, though at first sight not so prominent. This is "the struggle for existence," a phrase which has of late years become exceedingly familiar, though the facts of which it is the expression are not quite so generally understood. We have long known that in thickly-populated human communities there is a struggle for existence. But there is another struggle more ancient still. It dates from the first appearance of created beings on the earth, and it has been raging ever since with a fury which, if quieter, is not less keen than that with which, unhappily, we of the newer creation have been too long acquainted. Linnæus calculated that if an annual plant produces two seeds which shall arrive at perfection—though no plant produces so few—and each of these in turn perfects two, and so on at the same rate, at the end of twenty years the descendants of the original plant would be a million of individuals. It is reckoned that a single plant of groundsel (*Senecio*) may produce 6,500 seeds, one of chickweed (*Stellaria*) 5,000, and one of shepherd's purse (*Capsella*) 4,500; but what with overcrowding, and preying of insects, and other mishaps, usually looked upon as "accidents," very few of this enormous progeny ever reach maturity. Again, the *Orchis maculata* of our hedgerows (Vol. III., p. 366) produces so great a quantity of seeds, that were they all to spring up the earth would soon be covered with this plant, but in reality the Orchis in question is by no means a very common plant compared with others which seed much less freely. The botanist who thinks over these matters soon comes to the conclusion of Dean Herbert, that "plants do not grow where they like best, but where other plants will let them;" in other words, "climate and soil have not so much influence on the free growth of a plant as the presence or absence of other plants with which it has to struggle to maintain its existence." The American water-weed (*Anacharis*) was first recorded in Britain in the year 1847, yet in the interval it has spread with inconceivable rapidity over the country, extinguishing the native species with which it comes in contact, though it has never yet produced seed, and in America is not more troublesome than other weeds. The common sorrel (*Rumex Acetosella*) has been introduced with grain into nearly every one of our colonies, and in New Zealand it is spreading with such activity that it would take possession of the fields, did not the farmer find that in the struggle for existence it cannot bear up against the greater vigour of the white clover, which soon kills it. Even the white clover, in one locality, has its match in the cat's-ear (*Hypochæris radicata*), which in three years from the time of its introduction into New Zealand has destroyed excellent pastures. The introduction of the *Anacharis* into Great Britain is paralleled by the introduction of the *Vallisneria* into the Hudson River, where, in the months of August and September, it almost stops navigation in places; or by the water-cress which threatens to choke up the New Zealand Rivers in the district of Canterbury. The little duckweed has been driven out of a pool at Sandwich, in the Detroit River, in the United States, by *Wolfia Columbiana*, another water-weed which has recently made its appearance; and it has been repeatedly noticed that, after a few years of settlement, the introduced plants expelled the aboriginal vegetation from the prairies. A grass (*Stipa textilis*) has invaded the southern Russian Steppes, and is rapidly displacing almost every other plant, while the cardoon—a tall thistle (*Cynara cardunculus*), accidentally introduced from Europe, now clothes, almost to the exclusion of other plants, whole leagues of the Pampas of the Argentine Republic and Uruguay. Altogether it would appear that in the struggle for existence between the denizens of the Old and New Worlds, the former are usually victorious. In New Zealand we see this struggle particularly well exemplified. The Maories have even recognised it in a proverb to the effect that as "the white man's rat has driven away the native rat, as the European fly drives away our own, and as the clover kills our fern, so will the Maori disappear before the white man himself."

In reality, when we talk familiarly of a plant being "rare" or "common" we condense into these two words a world of fact and theory. A plant is not, as we have seen, common because it produces a great quantity of seeds, or rare because it produces few. "When we look," writes Mr. Darwin, "at the plants and bushes clothing an entangled bank, we are apt to attribute their proportional number and kinds to what we call chance. But how false a view is this! Every one has heard that when an American forest is cut down a very different vegetation springs up; but it has been observed that ancient Indian ruins in the Southern United States which must formerly have been cleared of trees, now display the same beautiful diversity and proportion of kinds as the surrounding virgin forest. What a struggle between the several kinds of trees must have gone on during long centuries, each annually scattering its seeds by the thousand! What war between insect and insect—between insects, snails, and other animals, with birds and beasts of prey, all striving to increase, and all feeding on each other, or on the trees, their seeds and seedlings, or on the other plants which first clothed the ground, and thus checked the growth of the trees! Throw up a handful of feathers, and all must fall to the ground, according to definite laws; but how simple is the problem where each shall fall, compared with that of the action and reaction of the innumerable plants and animals, which have determined in the course of centuries the proportional numbers and kinds of trees now growing on the old Indian ruins." In reality, the equilibrium of species is preserved throughout the world in some particular locality by the number of foes or allies it may have among plants or animals inhabiting the same region, for the wars of the roses are perpetual wars.

How, then, were plants originally distributed? Naturally, no question in plant geography has given rise to more discussion than this. It lies at the bottom of the whole science, and the theories which have been adduced in explanation of the appearance of plants in the various regions of the earth would fill many pages, if even the elementary facts in connection with them were narrated. Linnæus, for example, imagined that plants were originally created on the sides of some lofty mountain in the tropics, where vegetation could find from summit to base every kind of climate. However, this hypothesis will not explain the peopling of cold regions, or how plants of these regions are not found in the intervening warm tracts of country. Buffon, on the other hand, seized the idea that all vegetation originated in the Arctic regions, and little by little spread southward, modifying itself according to circumstances. But this view is even less tenable than the other. Then, for long, botanists held in much favour the doctrine of "specific centres of creation," the leading idea of this hypothesis being, that there were throughout the world a number of points of special creation, each having a particular "flora" or assemblage of plants, from which points the species occupying the surrounding area have spread in a radiating manner. This was essentially the doctrine of De Candolle, who came to the conclusion that "the present species were brought into existence either in a single one or in a number of individuals in one or in different localities simultaneously, or more probably, successively, at a period or periods when the geological outlines of the surface of the globe were very different from what they are now—each species with characteristics and susceptibility of variation within definite limits, essentially the same as those it now possesses." These views of De Candolle, espoused at the time he wrote by the majority of naturalists, are now held by very few. The latest—and the favourite—theory is that "each species has been produced in *one* area alone, having subsequently migrated from that area as far as its powers of migrations and subsistence under past and present conditions permitted." Doubtless there are many difficulties in explaining how the same species could have migrated to the widely different points at which it is now found; nevertheless, these difficulties are gradually being cleared up, and the theory seems the safest as well as the most philosophical which the botanist can adopt. "He who rejects it," writes the most eminent of its supporters, "rejects the *vera causa* of ordinary generation with subsequent migration, and calls in the agency of a miracle." It must also be remembered that some of the methods by which plants—and animals—could have migrated in former times from one point to another, no longer exist, for the intervening land passages over which they gradually travelled are now broken down, and where once there was a continuous continent there is now only a landless sea. Yet, we must not be led away into supposing that in the intervening spaces between the two or more points where the same species is found, land invariably existed in former times—this idea having been carried to a dangerous extreme by Edward Forbes and his school. There are natural and other causes daily in operation, which will go far to explain the migration of species, without calling in the aid of catastrophes and cataclysms. Changes of climate must also, without doubt, have had their influence on migration. "A region, when its climate was different, may have been a high road for migration, but now be impassable." Changes in the level of land, and in the contour of continents, have had much to do with allowing terrestrial species to migrate to localities which they can no longer reach by similar means. This we may allow, without believing as Forbes insisted we should, that all the islands in the Atlantic must have been recently connected with Europe, or Asia and Europe, and even with America; indeed, it can scarcely be conceded, if this doctrine is to be carried out to its legitimate conclusions, that a single island exists which has not recently been united to some continent or other. Assuming that this was so in some cases, without particularly specifying the instances, and merely holding these causes in reserve to account for cases inexplicable on any other theory, we may consider how far occasional, or as they are frequently called, "accidental" causes have operated in taking the plants of one part of the world to other parts. A study of these causes serves in a certain degree to explain the phenomena of "dissevered species," that is, the same species being found in widely different parts of the world, or in localities very unlikely for its occurrence.

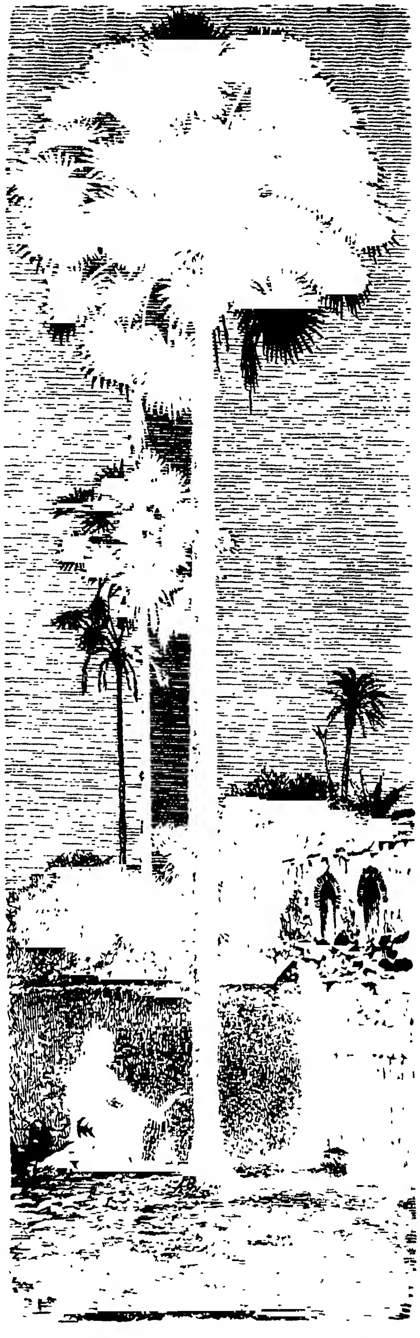

Fig. 2.—The Date Palm (*Phœnix dactylifera*).

Man, though the agent most recently and in fewest numbers at work, has perhaps more than any other aided in carrying the plants of one region to another, and in thus confounding the origin and distribution of species. Some of the ways in which he accomplishes this we have already noticed. Wherever he goes he carries the seeds of plants with him—the merchant in the packing of his goods, the colonist with his "penates," and more directly among his cultivated grains and garden plants; and the march of armies over the world might even be traced by the plants which have sprung up in their tracks. The most carefully-cleaned grain will contain the seeds of the wild plants which have grown up and been reaped along with it, and as "ill weeds" proverbially flourish, they propagate rapidly until they gain a footing. This they usually maintain, and in many cases, we have seen, do so to the prejudice of the indigenous flora. The seaman brings plants with his ship's ballast from distant lands, the climate of which is often similar to that of the country in which he shoots it to make room for his merchandise. Accordingly, every botanical collector knows that there are numerous foreign plants to be looked for in any locality where ships are in the habit of discharging their ballast. Since the extensive introduction of foreign wools, many plants of the wool-producing countries—even of Australia—have sprang up in the vicinity of places where the wool is washed and bleached, though indeed, in most cases, these exotics last only one season. Escapes from gardens, like the American *Mimulus luteus*, which is now wild in every county from Cornwall to Shetland, also add to our flora. The stuffing of a bolster introduced *Asclepias carasavica* from Tahiti into New Caledonia. The thornapple, a plant of the East Indies and Abyssinia, has spread throughout Europe by the agency of gipsy quacks; and it is affirmed that the ejected stuffing of a bird-skin first scattered, two hundred years ago, the seeds of the now common Canada thistle into Europe. In St. Helena, at the time of its discovery, there were not over sixty species of plants in the island; its flora now comprises some seven hundred and fifty species, the vast majority introduced by man. The year after Thorwaldsen's sculptures had been unpacked in Copenhagen, twenty-five plants of the Roman Campagna sprang up in the court-yard of the Museum, the seeds having, of course, been introduced in the hay, straw, &c., which had accompanied the works of art from Rome. In the campaign of 1814, the Russian troops brought in the stuffing of their saddles seeds from the banks of the Dneiper and the Don to the valley of the Rhone, and even introduced the plants of the Steppes into the environs of Paris. The Turkish army, in its European incursions, left the seeds of Eastern plants to bloom on the ramparts of Buda and Vienna. The Walcheren expedition of 1809 brought *Lepidium Draba* to the Isle of Thanet, where for long it was a most troublesome weed. The rib-grass used to be known by the New England Indians as the Englishman's food, and in Oregon the wood sorrel is to this day styled the "Hudson Bay" weed, the fur-trading company of that name having the discredit of introducing it in seed wheat from England. Since the Franco-German war, the seeds of numerous Algerian plants have naturalised themselves on the camping grounds of troops brought from the African colonies, or where forage from the shores of the Mediterranean had been used. Finally, not to multiply, as could be easily done, endless instances of how man has altered and modified the flora of countries, it is curious to find that on the coast of Mekran the date palm (Fig. 2) is common, while in the interior it is confined to certain lines of country. The local explanation of this is afforded by an ancient tradition, which declares that the palms along these lines in the interior sprang up from the stones dropped by Alexander the Great's soldiers on their return march from India. This legend—which we have from Sir Bartle Frere—may or may not be fact, but it nevertheless illustrates the persistence of popular belief in the agency of man in distributing plants. The winds—though not to quite such an extent as superficial observation would lead us to believe,—migratory birds to a greater degree, quadrupeds by carrying seeds which have fastened on their hides, rivers in a marked manner, currents of the sea, and even icebergs and ice-fields on a very small scale, aid in gradually conveying the seeds of plants from one country to another, and in altering the flora of the wide regions over which they act. Not a great many seeds can survive long immersion in sea-water, and even when they can, it is not always that the current into which they may have dropped runs from a country the climate of which is similar to that on the shores of which it casts them, to allow of the seed living, even when it is fortunate enough to be tossed out of reach of the waves and take root. There is, however, a strong suspicion that at least one American plant, *Eriocaulon septangulare*, has been brought to our shores by currents. It is found on the Island of Skye, and some of the neighbouring Hebrides, and on the West Coast of Ireland, into both of which districts it may have been washed by the Gulf Stream. Migratory insects may also aid in distributing, as they certainly help in devouring the produce after distribution. It has, for instance, been noticed in the Cape of Good Hope that plants, new to a locality, sprang up after the visit of a swarm of locusts. It also follows, if what we have said about the fertilisation of certain plants by insects be true, that the distribution of many plants will depend upon the presence or absence of the insect necessary for their fecundation.

There has, however, been a still more ancient migration of plants, when the conditions of the earth were much different from what they are at present, and to this cause is attributed, among other peculiarities of plant distribution, the marked Alpine flora, which consists of Arctic plants driven south during the glacial period, but now left stranded on the tops of mountains, prevented from penetrating to the plains below, owing to the barriers which the climate presents in their way. But the peculiarities of the Alpine flora are too wide a subject for discussion in this preliminary sketch, while the extremely interesting and suggestive peculiarities of the island floras have already been sufficiently described,* though the study of the various continental contributions to that of the British Isles affords material for curious commentaries on the facts we have noted. In books on botanical geography there will usually be found descriptions, more or less fanciful, of certain botanical regions from the equator north and south, or which occupy certain more or less circumscribed areas over the whole world. It must, however, be understood that they merge into one another, and are by no means so hard and fast as they seem on the map. In our Frontispiece we have sketched these botanical regions—in each of the regions there being certain groups of plants peculiar to it, though in all probability in no large part of the world is there actually an assemblage of plants which are one and all found nowhere else. All that is meant by these so-called botanical regions† is that within each of them there are certain more or less peculiar groups of plants, or certain aspects of vegetation, which at once give them a character of their own. Mr. Bentham, perhaps, puts the whole question in the proper light when he remarks that there are "regions of vegetation depending on physical and climatological considerations, which influence chiefly the areas of individual species or varieties, and botanical regions depending on community of origin or genera. By the combined effect of these two agents, whenever the uniform action of the one upon the other has been promoted by the continuance of geological repose and maintenance of impassable barriers, many species, genera, or even natural orders, have been gradually produced, or introduced, and maintained in certain territories, whilst they have never appeared, or have become extinguished, in others, so as to have given to every territory or district a special botanical character; and thus real regions have been formed, exceedingly unequal in size, definiteness of circumscription, and intensity of specialisation (distinctness of character), but which it is very instructive to study and compare, and must therefore be named and described. We must also admit that every race has probably been the offspring of one parent or pair of parents, and consequently originated in one spot; but we must also insist that it may have been widely spread for years or ages, before it became formally differentiated—perhaps under conditions and in countries different from those which gave it birth—and that the idea of general centres of creation whence the flora of a region has gradually spread is a perfect delusion."‡ There can, for example, at once be detected a northern type, a tropical type, and a southern type, each of which can again be subdivided in minor—yet great—districts, such as those which are sketched in the map.

Plants also vary in their characters, in so far that some are more or less cosmopolitan. Others again are confined to small extent of country. For instance, *Origanum Tournefortii* is found only on one rock in the small island of Amorgos, in the Greek Archipelago; *Disa grandiflora*, an orchid, is peculiar to Table Mountain at the Cape of Good Hope, as is also said to be another orchid, *Cymbidium tabulare*. The cinnamon, though cultivated in various countries, is generally believed not to grow wild out of the Island of Ceylon, nor coffee to be indigenous to any region save Abyssinia. *Araucaria excelsa* is limited to Norfolk Island, and the cedar of Lebanon is confined to one or two localities in Syria and Algiers. Even in a country there are local species, found however in other countries more widely distributed. Thus, *Oxytropis campestris* is confined in Britain to one spot in the Clova Mountains, in Scotland. *Cotoneaster vulgaris*, though scattered over Central, Southern, and Eastern Europe, and Central Asia, in our island alone affects the limestone cliffs of Great Orme's Head, in Wales; and the otherwise widely-distributed *Potentilla rupestris* is in Britain found only on the Breiddin Hills, in Montgomeryshire. Again, in the Seychelles, the species of pitcher plant (*Nepenthes*) peculiar to that group is confined solely to one mountain summit of one of the islands, and it is well known that the giant trees of California (*Sequoia gigantea*) are nowhere found out of that State, and even there in only one or two very circumscribed localities.

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* "Oceanic Islands"—"Science for All," Vol. II., pp 320—328.

† The main details are taken from the late Professor Grisebach's "Die Vegetation der Erde nach ihrer Klimatischen anordnung" (1872), but in some respects they have been altered, and the approximate ranges of economic plants have been added on the authority of data obtained from numerous other published and unpublished sources of information.

‡ "Presidential Address to the Linnean Society" (1869), p lxxviii.

To sum up the main facts arrived at from the study of a subject which is one of the greatest and most interesting in all botanical science—no species of flowering plant grows in every part of the world, though flowerless plants, like lichens, mosses, and ferns, are more cosmopolitan. A flowering plant may be found in the Arctic and temperate regions, and then, after missing a wide intervening region, appear in the southern temperate and Antarctic regions; but none range from pole to pole. It has been shown that there are only about eighteen species which may be said to extend over a space equal to something like half the earth. Those which extend over an area equal to about the third of the world do not exceed one hundred and seventeen, and of these the woody species have the narrowest range, and the majority are inhabitants of the temperate and frozen regions of the northern hemisphere. Another very remarkable fact is, that every species which at once exists on two continents is also found in the intermediate islands.

Botanical geography is, however, even yet only in its boyhood, for we are ignorant, among a thousand other salient points, of the causes which operate in preventing, or permitting, acclimatisation, and of the origin of any one of our cereals and other cultivated plants. The science, to use the words of Schleiden, is still young, and "burdened with all the faults of youth, overflowing with the fulness of life, certain of a fair and powerful manhood, but still disorderly and obscure, gathering much at present unintelligible for use in riper years, and as yet dreaming more than thinking."

AN ECLIPSE OF THE SUN.

By W. F. Denning, F.R.A.S.

PRE-EMINENTLY calculated, from the striking nature of their effects, to form one of the grandest sights in nature, it is not to be wondered at that total solar eclipses have been the source of amazement to the uninformed and the subject of frequent allusion by the historian; and it is unfortunate that the extreme rarity of the spectacle is such that comparatively few people have ever witnessed it. Unless a person has been privileged to accompany one of the expeditions specially equipped to investigate and record an occurrence of this kind, or unless he chances to reside on that particular tract of the earth's surface over which the line of totality passes, he will never, perhaps, have the opportunity of witnessing this grand celestial sight. It is not because a total solar eclipse is a phenomenon which rarely happens that it is but seldom observed, for if we consult a catalogue of eclipses we shall find at once that they are of somewhat frequent occurrence. It is rather because they are visible only from a very limited area of the earth's surface that they form an event of exceptional rarity; so that if we await the phenomenon at any particular station, many generations may pass without the expected gratification afforded by the view of so unique an occurrence. More pointedly, if we earnestly desire such an observation, we must go to the eclipse and not wait until it comes to us. Englishmen who do not travel have not seen a total eclipse of the sun since 1724, for though, many times subsequently to that remote epoch, the sun has been largely hidden, it has never been absolutely obscured in total eclipse to observers in this country.

It is not difficult to understand that, in ancient times, when extremely vague ideas prevailed with reference to natural phenomena, eclipses filled mankind with a good deal of superstitious terror. The darkness of premature night descended upon the earth unexpectedly and suddenly, and men stood amazed at the unwonted withdrawal of the source of light. Weird shadow-bands fell over the landscape, giving earth and sky alike an unnatural aspect. As the darkness deepened the planets and brighter stars began to shine as at evening, birds went to roost, and the animal and vegetable world made preparation as for the night. What stupendous influence could have thus so completely robbed the sun of his lustre? what dark body was that which, encroaching at first merely as a notch upon the sun's west limb, had gradually worked itself over the whole surface, until now the bright sphere was almost entirely obliterated and effaced from the heavens? Would this spectral darkness be yet further intensified and sustained, or would the sun be able to relieve himself from the burden of the overshadowing monster? An appalling anxiety possessed the observers; but soon, as they tremblingly looked upwards again, the indications of returning day became apparent, the shadows were beginning to be dispelled, as a slender crescent of the sun had just begun to reappear, increasing as time wore on, until, after a short interval, the solar orb had completely freed himself, and the opaque obstructing body, whatever it was, had wholly disappeared; all fears were relieved—the oppressive darkness had dispersed, and animate nature quickly resumed her customary avocations.

Let us proceed at once to the simple explanation of the theory of solar eclipses.

A self-luminous body, like the sun, scatters light in all directions, and when the rays fall upon a non-luminous body they are intercepted from the space immediately behind it, and a shadow is thrown a certain distance in that direction. Now another celestial body, deriving its light also from the sun, will, upon entering the area over which this shadow is cast, manifestly be deprived of its lustre and suffer obscuration, either wholly or in part, during the entire period of its immersion. This is what happens to the earth in the case of a solar eclipse. The sun and earth revolve in the plane of the ecliptic, and the moon, being but slightly inclined to that plane, interposes between them once in every revolution (*i.e.*, at new moon), so that it happens they are sometimes all three in the same line. When this occurs a portion of the moon's opaque sphere is seen projected upon the sun's face, intercepting his light in a degree proportionate with the magnitude of the eclipse, which depends upon the distances separating the centres of the sun and moon at the middle of the phenomenon. Only in cases when these centres precisely correspond can there be a total obscuration, because the apparent diameters of the two bodies are nearly identical.

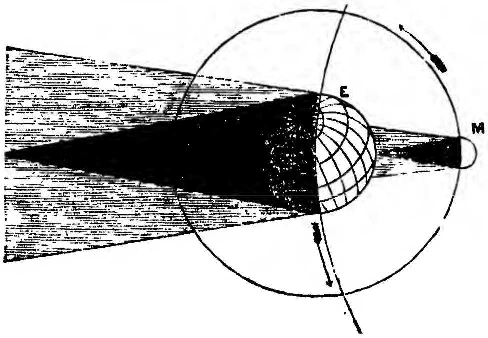


Fig. 1.—Diagram illustrating an Eclipse of the Sun.

Let S (Fig. 1) represent the sun, M the moon, and E the earth. The two latter bodies being non-luminous, each project shadows termed the umbra and penumbra. The umbra is a dense shadow; any object becoming immersed in it suffers total eclipse. The penumbra is a fainter shadow, giving partial eclipse. During a total eclipse of the sun, the moon (M) being very slightly greater in apparent size than the sun, throws her dark shadow only upon a small area of the earth's surface situated in the central line of the eclipse. The outlying penumbra covers a far greater expanse of the surface, giving a partial eclipse everywhere within its limits.

The sun would suffer eclipse at every new moon (at intervals of 29½ days) were the orbit of the moon situated in exactly the same plane as the ecliptic, but the inclination amounts to some 5°; hence the moon at conjunction frequently passes above or below the sun, and thus evades the necessary conditions of an eclipse. It is when the moon crosses the ecliptic at the time of the new that a solar eclipse must result, inasmuch as her position is then precisely between the earth and sun.

The word *eclipse*, as applied to these obscurations of the sun, is sometimes questioned as not being strictly accurate—for a celestial body when eclipsed must be immersed in a shadow. Now, we have shown that a solar eclipse is caused by the projection of the moon's dark body upon the sun, which is equivalent to an *occultation* in cases of total eclipse, but when the apparent diameter of our satellite is less than that of the sun, as in annular eclipses (Fig. 2), the event is really a *transit* of the moon across the sun. In annular eclipses the moon's dark shadow falls short of the earth, as in the figure, for the moon being less in visible dimensions than the sun cannot wholly intercept his rays, and only a partial eclipse results.

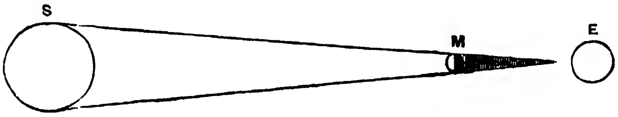
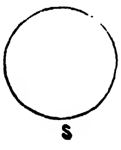


Fig. 2.—Theory of an Annular Eclipse.



The Chaldæan shepherds foretold eclipses, even before the nature of such phenomena was thoroughly understood, by their regular recurrence after a certain interval. The moon's "nodical revolution" is performed in 27d. 5h. 5m. 36s., which is more than two days shorter than her "synodical period" (or the time occupied in passing from one new or full moon to another) of 29d. 12h. 44m. 3s. Now 223 of the latter periods extend to 18 years

10 days and $7\frac{3}{4}$ hours (or 6585·32 days), and 19 revolutions of the sun are performed, with regard to the lunar nodes, in 6585·77 days. The correspondence of the two periods originates the recurrence of eclipses, both solar and lunar, at intervals of 18·03 years. This period was known as the *Saros*. By adding it to the date of an observed eclipse the approximate date of its repetition was readily computed, though it must not be supposed that it supplied the data for determining the magnitude of the eclipse, as the conditions are slightly different at each recurring saros; nor, in the case of solar eclipses, which are observable only from small tracts of the earth's surface, was it possible by the aid of this cycle to foretell the particular locality over which the moon's shadow would be cast. But in a general way the method was found both convenient and accurate, and for many ages the ancients successfully availed themselves of its means to predict the times of these phenomena.

At each return the conditions of an eclipse are slightly different, so that the magnitude either increases or diminishes at each repetition. Those eclipses of the sun which occur at about the descending node, and are visible at first from the earth's South Pole, creep northerly at their successive returns, until ultimately they quit the earth at the North Pole. And the reverse is the case with those eclipses which, taking place near the ascending node, come in at the North Pole of the earth, for they gradually, at each recurring *saros*, become more southerly, until their final disappearance off the South Pole. Thus a very small eclipse came on at the North Pole on June 24, 1313, O.S., which finally leaves the earth on July 31, 2593, after seventy-two reappearances. To illustrate the matter further let us refer to the eclipse of July 14, 1748.* "This eclipse, after traversing the voids of space from the creation, at last began to enter the *terra Australis incognita* about eighty-eight years after the Conquest, which was the last of King Stephen's reign. Every Chaldæan period it has crept more westerly, but was still invisible in Britain before the year 1622, when on April 30 it began to touch the south part of England at about two in the afternoon. Its next visible period was after three Chaldæan periods, in 1676, on June 1, rising central in the Atlantic Ocean, passing us at about nine a.m., with four digits eclipsed. It was visible again in 1694 in the evening, and in 1730 (July 4) was seen above half eclipsed just after sunrise. Eighteen years more afforded the eclipse of 1748 (July 14). The next visible return was in 1766 (July 25), about four digits, and after two more periods, in 1802 (August 16, O.S.), about five digits. Again in 1820 (September 1, N.S.), it recurred as a large partial eclipse, and was well observed in England, the sky being generally clear. It was not visible again until 1874 (October 10), five digits. In 1892 the sun will go down eclipsed at London, and again in 1928 (November 12) there will be two digits obscured at London. But about the year 2090 the whole penumbra will be worn off, whence no more returns of this eclipse can happen till after a revolution of 10,000 years."

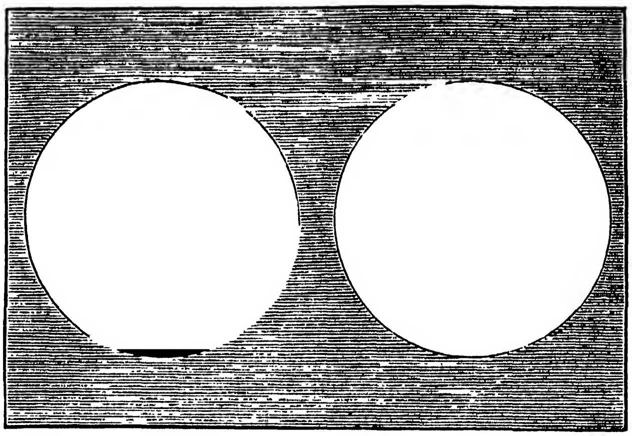


Fig. 3. Fig. 4.

Fig. 3.—Partial Eclipse. Fig. 4.—Annular Eclipse.

Partial eclipses (Fig. 3) are those in which a segment only of the sun's face is hidden by our satellite at the time of greatest obscuration when she passes either a little above or below the sun's apparent centre. They may be large or small, according to circumstances, and are usually expressed in digits or twelfth parts of the solar surface, so that an eclipse of three digits notifies an obscuration of a quarter of the sun, of four digits one-third of the sun, of six digits one-half of the sun, and so on The "Nautical Almanack," however, gives more precise details of the magnitude of eclipses, the sun's diameter being considered = 1, the portion eclipsed is represented by thousandths. Thus, there are two partial eclipses of the sun in December, 1880, the first of which, on Dec. 1, is a very insignificant one of 0·040 (which is equivalent to $\frac{1}{25}$th part of the solar disc), and the second, on Dec. 31, equals 0·717. Only the latter, however, is visible at Greenwich as a small eclipse of about two-fifths of the sun.

Annular eclipses (Fig. 4) refer to those in which a marginal ring of the sun's disc is visible, though the apparent centres of the sun and moon correspond exactly in position. In fact, the diameter of the moon being slightly less than that of the sun, it must obviously fail to completely obliterate his luminous disc, and there is still a narrow circle of light visible all round the border indicating this. The sun when nearest to the earth has an apparent diameter of 32½ minutes of arc, and the moon at apogee—*i.e.*, at her greatest distance from the earth—is less than 29½, and if a solar eclipse happens under these conditions it must essentially fail to be total. On the other hand, the moon at perigee subtends an angle of 33′ 31″, and the sun at greatest distance (when the earth is in aphelion) one of 31′ 32″, so that an eclipse occurring with these circumstances may be total if the centres of the two bodies exactly overlie at the instant of conjunction.

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* "Ferguson's Astronomy," 1772, pp. 232-3.

Beaded eclipses (Fig. 5) distinguish a phenomenon sometimes observed immediately preceding or following total obscuration, when the very narrow crescent of the sun is seen separated into a number of bead-like appearances—bright points alternate with dark spaces all along the limb. They were first described by Mr. Francis Baily during the eclipse of 1836, and hence acquired the appellation of "Baily's beads." The phenomenon has been thus explained:—The contour of the moon is not perfectly circular, for as seen projected upon the sun in solar eclipses it presents a serrated or jagged outline, due to the mountainous nature of her surface; and it is obvious that as this serrated figure steals closely towards the sun's interior margin the dark mountain peaks will first envelope it, while the intervening valleys will still allow fragments of sunlight to be discernible. This must occasion a series of luminous points on the affected limb, giving rise to the bead-like appearances so often described by observers.

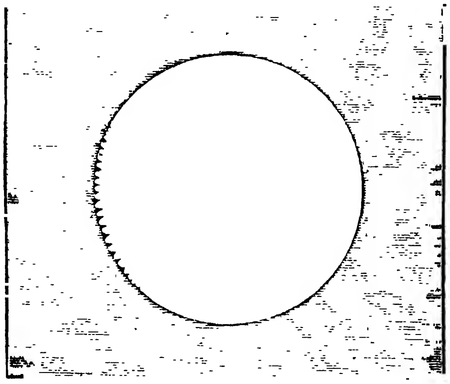

Fig. 5.—Beaded Eclipse.

Mr. Dunkin observed the total eclipse of July 28, 1851, at Christiania, Norway, and thus describes the apparition of "Baily's beads," which he recognised both before and after the total phase:—"About fifteen seconds before the beginning of total darkness the narrow line of the sun broke up into numerous small particles or beads of light. They were of different sizes, some being merely points, while others appeared elongated. Their appearance was of intense brilliancy, and the only thing with which I can compare it is a necklace of diamonds. The effect on the mind at their formation was quite overpowering. I was unprepared for so magnificent a sight. At the reappearance of the sun the same general appearance of the phenomenon of 'Baily's beads' was exhibited, but the effect on the imagination was not so striking, though the brilliancy of the beads seemed equal to that noticed at the commencement of totality."

But the chief phenomena of these eclipses, and one having many important bearings, is the *corona*, or halo of light (which apparently surrounds the dark image of the moon), and the flaming protuberances extending a considerable distance from the limb. These singular and almost startling appearances are invariably present in total eclipses, though in different forms and degrees; but we must content ourselves with a bare reference to the subject here, as it has been already discussed and illustrated in a former paper.*

The number of eclipses in any year cannot exceed seven, nor be less than two, in which case they are both of the sun. Solar eclipses are of more frequent occurrence than lunar eclipses, in the proportion of about three to two; yet the latter phenomena are more commonly observed, because they are visible from all parts of the earth's surface having the moon above the horizon, which includes an entire hemisphere, whereas the former are limited to a thin chord of the earth's surface, rarely exceeding 150 miles in breadth.

Since the eclipse of December 22, 1870, the eclipses of the sun visible in this country have been of small dimensions, and indeed there is no prospect of our witnessing a large eclipse until the close of the present century, viz., on May 28, 1900. In fact, we shall find, on consulting a list of these phenomena, that during nearly the thirty years included in this interval there is not one of considerable magnitude visible at Greenwich; yet during the quarter of a century preceding 1870 we had no less than six large eclipses, as follows:—

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* "Science for All," Vol. II., pp. 78—83.

Date.	Mag.	Date.	Mag.
1847—Oct. 9 . .	0·919	1860—July 18 . .	0·830
1851—July 28 . .	0·815	1867—Mar. 6 . .	0·750
1858—Mar. 15 . .	0.976	1870—Dec. 22 . .	0·814

The eclipse of 1847 was the largest since 1764, and was annular in the south of England. That of 1858 was also annular, and very nearly total. At Swindon, in Wiltshire, it was considered that $\frac{909}{1000}$ths of the sun would be obscured, so closely did the eclipse reach the conditions of totality; but this phenomenon occurred just at a time when the generally overcast state of the sky prevented observation nearly everywhere in England.

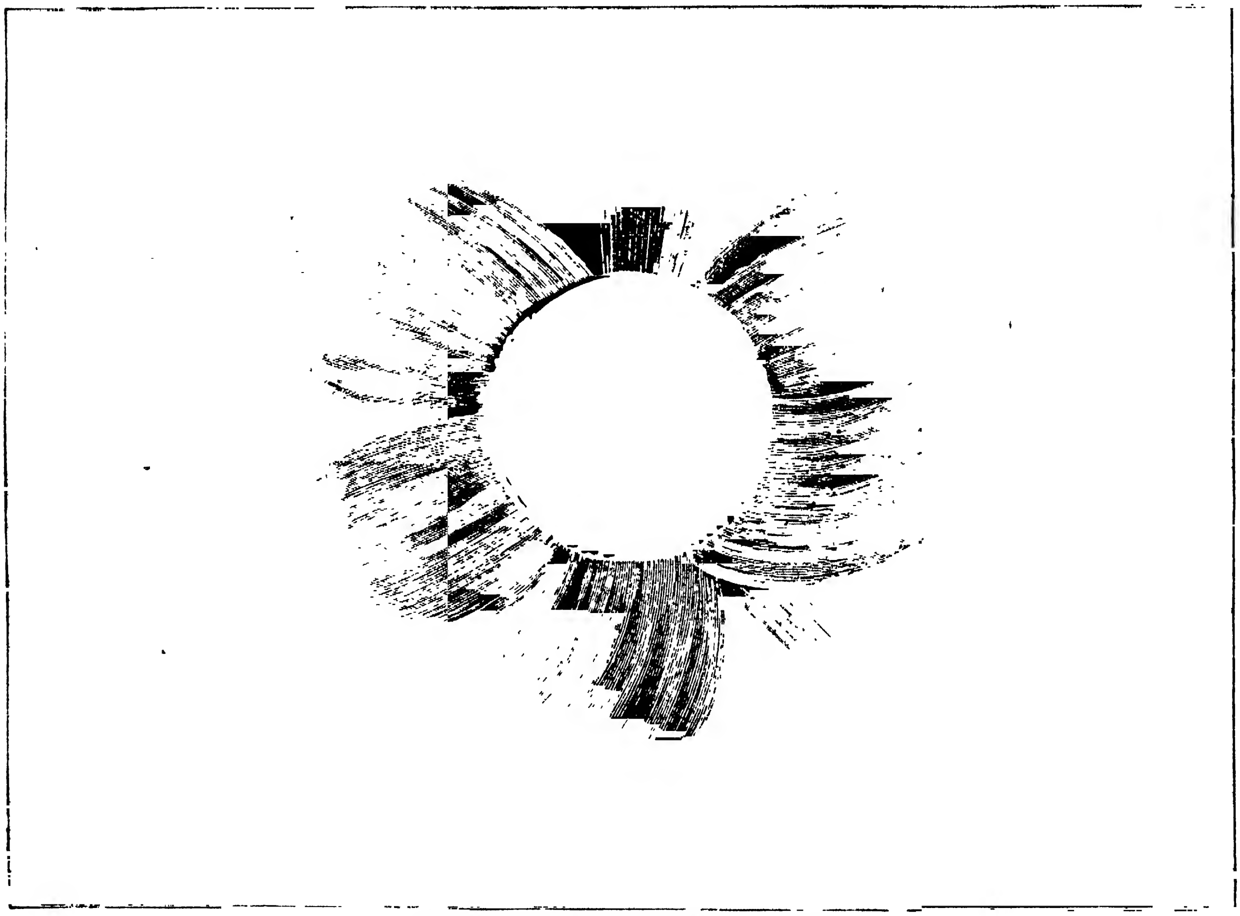

Fig. 6.—The Total Eclipse of July 29, 1878.

The next total eclipse visible in this country appears to be that of June 29, 1927, which will be best observable in the north of England, but totality will last only a few seconds. The next following that will be in 1999 (Aug. 11), total in the S.W. corner of England. Others will succeed in 2090 (Sept. 23), 2135 (Oct. 7), 2151 (June 14), 2200 (April 14), &c.

We have already said that the visible eclipses of the sun for the remainder of this century will be small and unimportant. Those of the next century will include some fine eclipses, as follows*:

Year.	Date.	Middle.	Digits.
1905 .	Aug. 30 .	. 1 p.m. .	. 10
1912 .	April 17 .	. 0½ p.m. .	. 11
1914 .	Aug. 21 .	. noon .	. 8
1921 .	April 8 .	. 9 a.m. .	. 10
1925 .	Jan. 24 .	. 3¾ p.m. .	. 7
1927 .	June 29 .	. 5¼ a.m. .	. 11
1945 .	July 9 .	. 2 p.m. .	. 7
1954 .	June 30 .	. 0½ p.m. .	. 10
1961 .	Feb. 15 .	. 7½ a.m.	--
1971 .	Feb. 25 .	. 9½ a.m. .	. 7
1996 .	Oct. 12 .	. 2½ p.m. .	. 7
1999 .	Aug. 11 .	. 10 a.m. .	. 11

The largest eclipses of the twenty-first century will be:—2015 (Mar. 20), 2026 (Aug. 12), 2075 (July 13), 2081 (Sept. 3), 2090 (Sept. 23), and 2093 (July 23). In the twenty-second century there will be four great eclipses, as follows:—2135 (Oct. 7), 2142 (May 24), 2151 (June 14), and 2200 (April 14).

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* Compiled from a table of future eclipses by the Rev. S. J. Johnson in his work on "Eclipses, Past and Future," pp. 92-3.

Not a single eclipse of the sun (total) at Greenwich may be expected to occur during the next 600 years—a fact which in itself sufficiently proves the great rarity of such a spectacle at any given point of the earth's surface.

The last two eclipses total in England occurred nearly together—viz., on May 2, 1715, and May 22, 1724, with an interval of nine years, or half a Chaldæan period. Indeed, it not unfrequently happens that large solar eclipses succeed each other at this interval; for example, we may refer to those of 1833, 1842, 1851, and 1860. According to Halley no total eclipse was observed at London between March 20, 1140, and April 22, 1715 (O.S.).

The eclipse represented in Fig. 6 was observed and depicted by Mr. F. C. Penrose from the outskirts of Denver in Colorado. Some remarkable streamers, probably of meteoric origin, were seen emanating from the sun during the period of totality. The figure shows the blackness of the moon as compared with the sky on which the corona was projected. To the north and south the sky seemed much darker than in the east and west. In the telescope some difficulty was experienced in fixing the limits of the corona in the latter directions, but the naked eye observations showed that the coronal streamers extended many lunar diameters in each direction of the ecliptic, especially westward.

Total eclipses of the sun are necessarily of very brief duration, never exceeding a few minutes. This will be evident on a consideration of the elements involved. The maximum apparent diameter of the moon being 2,011″, and the minimum apparent diameter of the sun being 1,892″, there is a difference in size of only 119″ under the most favourable circumstances of totality; and when it is remembered that the moon's synodic velocity carries her on 30″ in a minute of time, we shall understand at once how the transient character of these total eclipses are to be accounted for. We can also perhaps appreciate the anxious feelings of observers of such phenomena who may have travelled many hundreds of miles to note the important details manifested during the short interval. Every moment must be utilised in recording the impressive and varied stages of its progress. The effects upon surrounding objects are startling. The observer, withdrawing his eye from the telescope and looking round, sees an unnatural gloom has settled on the landscape, the faces of persons standing near have assumed an unearthly aspect, the planets and brighter stars have come out, and indeed the spectral, shadowy nature of the unique spectacle before him is such that, while it defies felicitous description, it can never be effaced from the memory.

The visibility of bright stars near the sun during the short period of totality has suggested that, should a new planet exist between Mercury and the sun, the occasion would be extremely favourable for its detection. At other times it would be invisible, from its constant proximity to the sun, and would obviously never be visible as a morning or evening star, for at greatest elongation it would never depart more than a few degrees from his side. Now during the eclipse of July 29, 1878, a star was seen by two observers independently which could not be identified with any known celestial object, and the inference was that it must be the suspected intra-Mercurial planet *Vulcan*. But the observation led to nothing definite, and the existence of the long-sought planet cannot yet be regarded as established. It is a point to which the attention of future observers should be directed, for the transit of perfectly opaque circular spots across the sun's disc has been occasionally observed, and a planetary origin must be ascribed to such bodies, as they have exhibited distinct peculiarities of appearance and motion, quite different from the ordinary solar spots. As to the latter phenomena, they are generally visible; and it is an interesting feature of solar eclipses to watch the moon's dark limb encroaching upon them, and, after their temporary obscuration, to

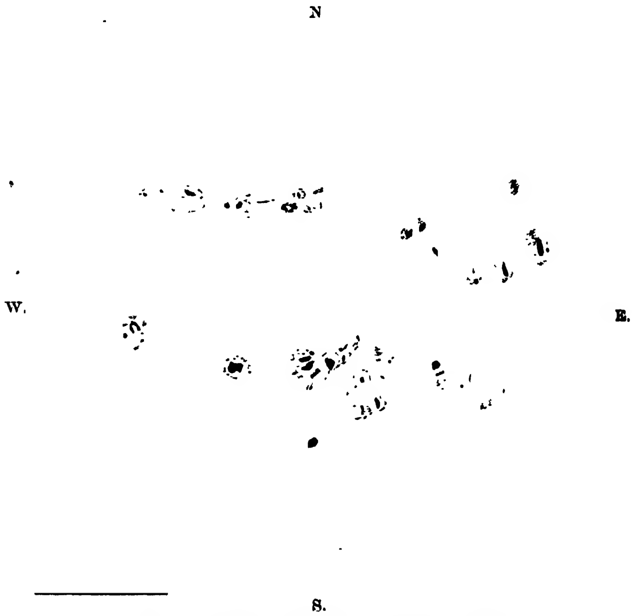

Fig. 7.—Spots on the Sun, October 29, 1868.

note their successive reappearances. These solar spots are sometimes very numerous and varied, as in October, 1868 (Fig. 7).

The intense glare of the sun renders it necessary in observations of solar eclipses to protect the eye with coloured glass. The phenomenon is then conveniently witnessed through its various stages, and if a telescope provided with such a glass is at hand, the interesting features of the occurrence may be fully brought out. Occasionally, when the eclipse happens with the sun at a low altitude, there is sufficient mist to moderate his intense lustre to a suitable degree, and the progress of the phenomenon is watched with great facility. This happened before sunset on October 8, 1866, when the sun became immersed in a band of fog lying over the western horizon, and the eclipse then taking place afforded a striking spectacle to many observers.

The ancients connected eclipses with the chief contemporary events of history. Ricciolus has indeed given a list of eclipses, with their historical relations. Among them we find the following:—B.C. 585 (May 28), an eclipse of the sun, foretold by Thales, by which a peace was brought about between the *Medes* and the *Lydians*; B.C. 431 (August 3), total eclipse of the sun—a comet and plague at Athens; B.C. 168 (June 21), a total eclipse of the moon—the next day Perseus, King of Macedonia, was conquered by Paulus Emilius; A.D. 306 (July 27), an eclipse of the sun—the stars were seen and the Emperor Constantius died; A.D. 1133 (August 2), a terrible eclipse of the sun—the stars were seen; a schism in the Church occasioned by there being three Popes at once. But the earliest eclipse of which a good record is preserved occurred on June 15, in the year 763 before the Christian era, at Nineveh, where it was nearly total. An inscription on the Assyrian tablets in the British Museum relates to this phenomenon, which appears to have been a very startling one on account of its great magnitude.

A CLOD OF CLAY.

By F. W. Rudler, F.G.S.,

Curator of the Museum of Practical Geology.

WHAT can seem at first sight to be less promising as the subject of a scientific essay than a clod of clay? We may watch the navvy as he digs into the stiff dull-coloured earth, but our curiosity is not easily excited by the heavy and shapeless lumps turned over by his spade. Yet to an inquiring mind, always athirst for knowledge, there are two questions immediately suggested by even the most unattractive object. Whether the object be natural or artificial, we spontaneously ask on first seeing it—"What is it made of?" And as soon as a satisfactory answer has been vouchsafed to this inquiry, we as naturally put this second question—"How has it been made?" In the case of a clod of clay it is by no means easy to answer these questions off-hand. On the one hand we must turn to the chemist, on the other to the geologist, in order, first, to determine the composition of the clay, and then to discuss the many problems connected with its origin.

But ages before the sciences of chemistry and geology took birth, men had been attracted by the curious properties of clay, and had learnt to skilfully utilise these properties in various ways. The early settlers in the valleys of the Euphrates, the Tigris, and the Nile did not overlook the remarkable plasticity of the clayey mud which existed in plenty beneath their feet; they soon recognised the ease with which it received the faintest impression when moist, the readiness with which it could be kneaded into any desired shape, and the hardness and durability which the same material presented after it had been dried in the sun, or, still better, baked by fire.

Such properties led to the extensive use of clay for building purposes in the early centres of civilisation; and the same properties still render it one of our most valuable materials for construction. Where stone is scarce, brick is so constantly employed that the expression "bricks and mortar" has come to be synonymous with an aggregation of human dwellings. Nor is it only as a constructive material that clay claims attention. From time immemorial the potter, like the brickmaker, has taken advantage of the remarkable set of physical properties possessed by clay, and not to be found in any other material. The plasticity of clay when damp, and its durability when baked, give to it an undisputed place as the basis of all fictile art. Whether it be the humblest piece of domestic earthenware, or the highest artistic effort of the porcelain-manufacturer, it is still clay that forms the raw material upon which the potter works. And in other ages clay has enjoyed a still wider range of utility. Among the ancient Assyrians and Babylonians, for example, a clod of clay was often used where we should employ a sheet of paper or a skin of vellum. Line upon line of arrow-headed writing was impressed upon the clay, and the tablet thus inscribed has come down to us as an almost imperishable monument of literary and historical interest (Fig. 1).

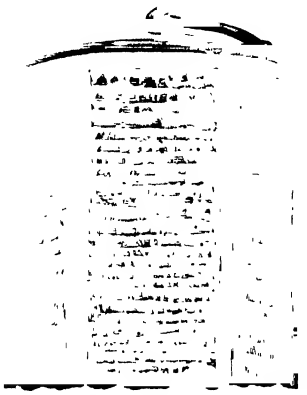

Fig. 1.—Prism of Baked Clay from Assyria, with Cuneiform Writing.

What, then, we may well ask, is the nature of the substance which from so early a period has been applied to such a multitude of uses? In approaching the study of clay it is not desirable to begin with a common clod, such as may be dug up anywhere in London, because this common clay is sure to contain various impurities which, by masking its properties, tend to complicate our inquiry. At starting, it is well to procure the clay in its purest possible form, and this we can fortunately do without going outside our own country. In certain parts of Cornwall and Devon there occurs a very pure clay, as white as chalk, and therefore utterly unlike our London clay. Since this white clay is found chiefly in Cornwall it is often called *Cornish clay;* and because large quantities of it are used in the Potteries for the manufacture of china or porcelain, it is also known as *china clay.* Scientific men, however, have yet another name for this material, more learned than those just given, but unfortunately much less expressive. It is known scientifically under the name of *kaolin.*

This curious word, kaolin, has been borrowed, like so many other things connected with the potter's art, from China. In the early part of the last century, a French Jesuit, named Francis Xavier d'Entrecolles, resided as a missionary at King-te-chin, one of the oldest and most famous porcelain-making localities in the empire. The Père d'Entrecolles numbered among his congregation many of the china-makers, and from them he obtained not only information about the manufacture, but also samples of the raw materials, which he sent home to France. Among these materials was the white china clay which he described as kaolin—a name signifying "high ridge," and being, in fact, the name of a mountain to the east of King-te-chin, where the material is worked (Fig. 2). D'Entrecolles, however, was neither mineralogist nor chemist, and appears to have erred considerably in some of his details—so considerably, indeed, that it is doubtful whether this white clay, after all, should really be called kaolin. But be that as it may, the name has become so familiar to scientific men that it would be useless to attempt to oust it from our nomenclature. In this article, therefore, we shall speak of the purest white clay indifferently as kaolin, or china clay, or Cornish clay.

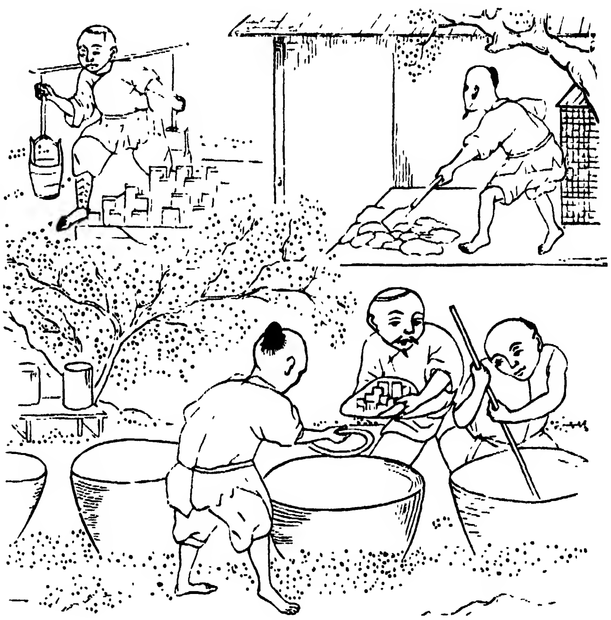

Fig. 2.—Chinese Clay-workers. *(From a Drawing by a Native in Stanilas Julien's "Histoire de la Porcelaine Chinoise.")*

If the reader has not lived in a district producing china clay, or in the Potteries, where it is so largely used, he has possibly never had an opportunity of seeing this material. Let us, then, suppose that a lump of china clay lies before him, so that he may make himself familiar with the substance and take stock of its physical characters. He will find it to be a soft, white, dull, earthy substance, rather greasy to the fingers when rubbed, especially if the clay be moist. Touched with the tongue, the kaolin slightly sticks to the moistened surface, much as a new tobacco-pipe adheres to the lips. When breathed upon, the kaolin emits a faint smell, such as may be perceived on examining any of moist clay. This smell is highly characteristic of clays and clay-like bodies, and is therefore termed an *argillaceous odour*.

Sight and touch and smell are of little or no avail when we pass from the physical characters of the clay to the deeper question of its chemical constitution. Mere inspection utterly fails to penetrate into the composition of the body, and appeal must needs be made to experiment. A lump of kaolin looks suspiciously like a lump of chalk; but a simple chemical test at once detects the difference. Drop a little vinegar or other acid on to the chalk, and effervescence immediately ensues, in consequence of the disengagement of bubbles of carbonic acid gas. Now treat the kaolin in the same way, and it will be seen that the acid produces no perceptible effect. One thing, therefore, is certain—whatever the kaolin may be, it is not chalk.

In an article on "Rubies and Sapphires,"* it was stated that clay is essentially a *silicate of alumina*; or, in other words, a combination of silica with alumina. No amount of ocular inspection could ascertain this fact—it is a fact which can be revealed only by delicate analysis in the chemical laboratory. One of the constituents, silica, is that kind of matter which occurs pure as rock crystal, while the other component, the alumina, is found to be the basis of the ruby. Yet the most searching microscope is powerless to reveal in a pure clay the slightest particle of either of these bodies. This is, of course, because the silica and the alumina exist in clay not free, but in a state of chemical combination.

In addition to the silica and the alumina, all clays contain more or less *water*. A clod of clay may be baked in the sun until it becomes so dry and hard that no one would suspect that it could still retain water in its composition. Nevertheless, this hard dry clay is a *hydrated* compound, containing water in a state of intimate combination with the silicate of alumina. The presence of this combined water is a point of great importance in the study of clay, since upon it depends, in large measure, the plasticity of the substance, or its power of being kneaded when moist.

It should be carefully noted that the water found in ordinary clay is not all in a state of chemical union. Part of the water in a clod of clay is but loosely associated with the material, having been mechanically absorbed by the clay and stored up in its pores; hence it is sometimes called *pore-water*, or *hygroscopic moisture*. Exposure to the temperature of boiling water gradually drives off this moisture, leaving the clay dry to the touch, but nevertheless containing much water in a more intimate state of association—water which is chemically combined with the clay, but still capable of removal by prolonged exposure to a high temperature.

When a clod of moist clay is kneaded into a brick and dried in the sun, it loses its hygroscopic water, and forms a mass sufficiently hard to be used for building purposes, at least in situations where it is not likely to be exposed to rain. Such sun-dried bricks were made in Egypt and elsewhere in the East at a very early period, and are still used to a limited extent in Mexico and other parts of Spanish America, under the name of *adobes*. In a moist climate, however, such bricks are utterly useless. A mass of sun-dried clay eagerly absorbs rain, and returns to its originally soft and plastic state; but when exposed to the action of fire, a radical change is effected in its composition and properties. Its water of combination is then more or less completely expelled, so that the well-burnt brick becomes a mass of dehydrated clay. Rain may fall upon the burnt brick and be mechanically absorbed, but this water does not re-enter into chemical union, and the clay consequently refuses to resume its natural plasticity. A thoroughly-burnt brick, or still better, a piece of pottery, may be reduced to powder and mixed with water, but the resulting mass, though moist, is utterly unlike the original clay.

Here, then, a fundamental change has been effected in the material, and a great advance thus initiated in the potter's art. It is obvious that until man had observed the remarkable change brought about by the action of fire on clay the use of pottery must have been exceedingly limited. Vessels of unbaked clay are of little use for holding liquids, since, by absorbing moisture, they become moist and sticky. It is often said that the ancient sepulchral urns which the antiquary unearths from beneath those barrows that formed the burial-places of many of our pre-historic ancestors are vessels of unbaked clay; but it may be safely asserted that unburnt clay could not be buried for twenty centuries without becoming soft and distorted in shape (Fig. 3). There can be little doubt, indeed, that these ancient British urns have been subjected to some degree of artificial heat—baked, perhaps, in the very pyre on which the body was reduced to the heap of ashes which the vase contains; but in many cases the operation of firing the vessel has been so crudely performed that the heat has not penetrated to the heart of the ware, and the clay is therefore but imperfectly freed from its water.

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* "Science for All," Vol. II., p. 362.

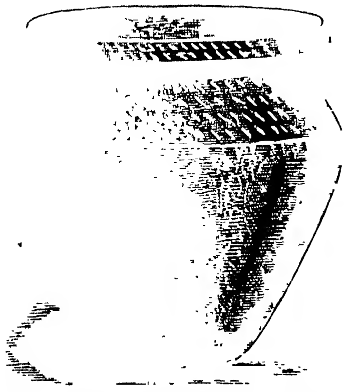
Fig. 3.—Ancient British Urn of Clay, "Bronwen's Urn," from Anglesey.

It has been said above that when burnt clay is exposed to moisture it absorbs the water without combining with it. This absorption of moisture shows that burnt clay is *porous*. For some purposes the porosity is an advantage, as in the case of water-coolers, where the absorbed moisture, finding its way through the pores of the vessel from within outwards, suffers evaporation on the outside, and thus robs the vessel and its contents of the heat which is necessary for the conversion of the liquid into vapour.

Porous baked clay is generally known as *terra-cotta*—an Italian term, meaning literally "baked earth." Valuable as terra-cotta is for certain purposes, its use is obviously limited. As a rule, we do not want vessels which have open pores, and we therefore generally coat the absorbent surface of the baked ware with a layer of *glaze*—a material which chokes up the pores and produces an impervious surface. The glaze is nothing more than a kind of glass, in some cases transparent, but in other cases more or less opaque; if opaque, however, it is generally termed an *enamel.*

When a piece of clay is dehydrated by baking or "firing," it shrinks, in consequence of the loss of water. Hence pottery of all kinds diminishes in volume during the process of manufacture. It has been shown by Dr. Aron that the amount of cubic contraction which clay suffers is exactly equal to the bulk of the water which has been expelled. This contraction proceeds equally in all directions, and therefore, while the *size* of a piece of pottery is less when baked than when raw, its *shape* remains unaffected.

Our study of the chemical composition of clay has led us, almost imperceptibly, to a brief consideration of some of the uses to which clay is applied. The transition has been perfectly natural, since these applications are dependent upon, and illustrative of, the chemical and physical characters of the material. But our study of kaolin remains exceedingly imperfect until we have made some inquiry respecting its origin. What, then, is the history of this pure white clay? By what natural operations has it been formed?

An answer to these questions is dimly suggested by observing the mode in which kaolin occurs. In Cornwall and Devon it is always found in association with granitic rocks, and in other countries it is invariably found in the neighbourhood of granite or of some rock more or less akin to granite. It has been already explained* that the kaolin results from the decomposition of one of the mineral constituents of granite, called *felspar.* In Fig. 1, p. 249, Vol. I., the felspar is represented by the large white parallel-sided crystals. Now in certain granites these crystals of felspar become altered, and ultimately converted into a soft white pasty substance. The white substance resulting from the decay of the felspar is neither more nor less than kaolin. The decomposed granite is known as *china-stone*, while a similar material containing more kaolin passes under the name of *china-clay rock;* the latter is termed by Mr. Collins *Carclazyte*, since the rock occurs typically at the Carclaze workings, near St. Austell, in Cornwall.

Up to this point, then, we have reached the conclusion that china clay is a product of the alteration of the felspathic component of granite or of some kindred rock. Let us now turn to the chemist, and inquire how such a change can be brought about. In this inquiry we shall be helped by comparing the composition of the felspar with that of the clay, by noting the difference between the original material and the derived product. The composition of felspar, however, is far from being invariable, and the mineralogist is familiar with several distinct kinds of felspar, exhibiting within certain limits considerable diversity of composition. But the commonest kind of felspar, and that which usually yields kaolin, is made up of silica, alumina, and potash. The clay, as already explained, contains silica, alumina, and water. Hence it appears that in order to convert felspar into kaolin we must remove potash and add water. True; but we must do more than this. The felspar contains about 65 per cent. of silica, while the kaolin contains only something like 45 per cent. During the alteration, then, a large proportion of silica has disappeared. In fact, it is not only the potash, but the silica with which this potash was combined, that has been removed from the felspar. The potash has, no doubt, been carried off in the form of some soluble compound, but the silica has probably been left to some extent behind. Mr. J. A. Phillips has found in some of the Cornish kaolin large crystals of quartz which exhibit at both ends well-shaped faces, and could therefore not have been planted upon a rock, since there is no apparent point of attachment. Hence it is suggested that these crystals have been developed in the soft paste, and represent in fact some of the silica which has been separated from the felspar during its degradation to the state of clay.

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* "A Piece of Granite:" "Science for All," Vol. I., p. 248.

In order to transform felspar into kaolin it is necessary to abstract the silicate of potassium and to introduce water. It has frequently been pointed out that such a change may be wrought by the action of air and rain, the alkaline silicate being thereby decomposed and the potash removed in solution as a carbonate, while the silicate of alumina remains behind in a hydrated condition, in the form of kaolin. Such an explanation is seductive by its simplicity, but unfortunately close observation shows that it does not exactly square with the facts. In short, the decomposition of granite and consequent production of clay is not most conspicuous in those situations where atmospheric action has been rife, but is in many cases to be observed in the deeper-seated portions of the rock where surface agencies can hardly have been at work. Hence many chemical geologists have felt compelled to evoke chemical agents of a more complex and potent kind, such as may be found in the subterranean circulation of waters containing hydrofluoric and boric acids. But into the chemical mysteries of these darksome depths we are not prepared in this paper to dive.

One of the most important practical differences between the china clay and the felspar from which it was produced lies in the diminished fusibility of the product. The potash in the original felspar plays the part of a flux, and promotes the fusibility of the mineral; but the clay, having lost all the alkali, is extremely difficult of fusion. Practically most clays contain impurities which act as fluxing agents, but in the case of "fire-clays" we have materials which are extremely refractory, and are therefore of great value, since they can be used in building furnaces, where they may be exposed to powerful heat without melting.

In consequence of the comparative infusibility of pure clay, it is impossible to make china of kaolin alone. Earthenware or pottery may be made without any fluxing material; but china or porcelain is a partially vitrified body, and therefore requires the presence of fusible materials in association with the clay. It needs no connoisseur to detect the difference between a piece of pottery and a piece of porcelain. Hold them in front of a strong light, and it is at once seen that while the earthenware is opaque the china is more or less translucent—that is to say, it allows some amount of light to be transmitted. This translucency is dependent on the presence of a glassy material associated with the grains of clay. In order to get this vitrifiable material the potter mixes the kaolin with *china stone* or *Cornish stone.* This, as explained above, is a kind of granite, having its felspar only slightly altered, and still retaining sufficient alkali to fuse into a vitreous mass. Those people who call china clay *kaolin* are in the habit of calling china stone *petuntse*, another of Father d'Entrecolles' Chinese terms, which appears to have become attached to the china stone without the slightest justification. Chinese scholars tell us that *tun* signifies "brick," and *pe* "white," while the termination *tse*, meaning "son," is used here as a diminutive, so that the entire expression *pe-tun-tse* is nothing but "a little white brick," and might with more justice be applied to the cakes of china clay than to the harder granitic rock.

Whatever confusion has crept into the use of these terms, there is no doubt about the fact that porcelain cannot be made without both the clay and the stone; the former is likened by the Chinese potters to the "bones" of their ware and the latter to its "flesh." It was ignorance of this fact—the necessity of using the two materials—that made the manufacture of porcelain for so many ages a profound mystery to Western nations, while it is a due appreciation of this fact that enables the modern manufacturer to produce such beautiful varieties of porcelain. The greater the proportion of the fusible constituent, within certain limits, the more delicate and vitreous is the china. A beautiful material, known as *ivory porcelain*, has of late years been produced by mixing the kaolin with felspar instead of china stone, and thereby obtaining a maximum of glassiness combined with great delicacy of tone.

During the baking of a piece of porcelain the material undergoes incipient vitrification, and this is necessarily attended by contraction of bulk. Hence a piece of porcelain shrinks during its manufacture, partly by loss of water, and partly by the closer union of its particles, due to imperfect fusion. Some natural clays contain so much alkaline material and oxide of iron that when highly baked they suffer a slight vitrification, and break with a close grain and a glassy texture; for it must be borne in mind that kaolin, which we have hitherto taken as the type of a clay, is a substance of exceptional purity, and that all ordinary clays are associated with more or less foreign matter, by which their physical and chemical characters are seriously affected.

In some cases the kaolin has been carried, by means of running water and other transporting agencies, to a considerable distance from its original source in the decomposing granite. During transit the clay will be separated, more or less completely, from the quartz and other minerals with which it was associated in its parent rock, and thus a deposit of clay may be formed by natural agencies, almost as pure as though it had been artificially prepared by careful washing. Such is probably the origin of the well-known clays which occur in the neighbourhood of Bovey Tracey, not far from the edge of Dartmoor, in Devonshire. This clay is known in the Potteries, from the place of shipment, as *Teignmouth clay*. It is generally believed by geologists that these clay-beds and the associated strata were deposited in a fresh-water lake, which received the waste brought down from the granite that forms the high ground of Dartmoor. Around the margin of this ancient lake, and in the neighbouring woods, flourished a prolific vegetation, which has left its remains in the shape of beds of lignite, or imperfectly formed coal, associated with the Bovey clays. The late Professor Heer, a distinguished Swiss botanist, sagaciously pieced together the waifs and strays of this old flora, and thus reconstructed the subtropical forests which existed in Devonshire at the time when the Teignmouth clays were in course of deposition—a time formerly referred to the miocene or oligocene, but recently to the eocene period. The commonest denizen of the ancient forests of Devonshire was a gigantic cone-bearing tree, closely akin to the mammoth tree of California, and named *Sequoia Couttsiæ* (Fig. 4).

While the counties of Cornwall and Devon yield those clays which have hitherto been described in this paper, we must turn to the neighbouring county of Dorset for the most important of all our plastic materials. In the Isle of Purbeck we find the clay which forms the staple of our common pottery. This clay is extensively worked in the neighbourhood of Wareham, and being exported to the Potteries from Poole Harbour, is often known as *Poole clay*. The geological position of this Dorset clay is said to be lower than that of the Bovey beds, most geologists placing it in that part of the *Eocene* strata which has been called the Lower Bagshot group. But Mr. Gardner has recently suggested that the Bournemouth and Bovey beds are on the same horizon, and regards them both as of Middle Bagshot age.

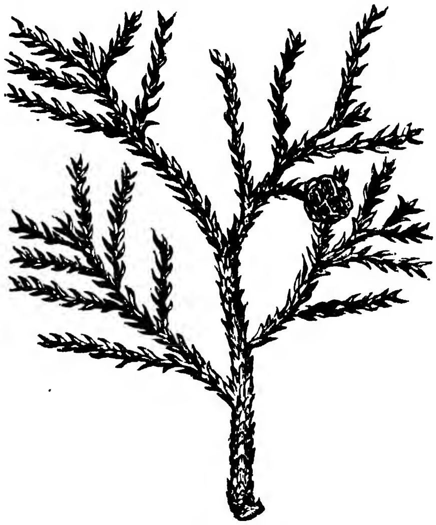

Fig. 4.—Branch of the *Sequoia Couttsiæ.*

Although the pipe-clays and potter's clays of Dorsetshire are more distant than the Bovey clays from any granitic rocks, it is nevertheless generally believed that they have a similar origin. The materials resulting from the disintegration of the granites of the Western hills might be carried by streams to a considerable distance, and the finer particles of clay would be retained in suspension long after the water had deposited the coarser part of its burden. If the current of the stream were arrested by the water spreading out into a lake, the finely divided matter would slowly settle and form a deposit of clay. Such is believed to be the origin of the Dorset clays—an origin very similar to that of the Devon clay; and the similarity is seen to be even closer when the fossil plants are put in evidence. Baron von Ettingshausen, M. De la Harpe, and Mr. J. S. Gardner have studied the flora of the Bagshot clays, and from the nature of this flora—with its palms, aroids, and cacti—have concluded that a sub-tropical climate must have prevailed in this country while the clays were deposited in the Dorsetshire lakes.

During the transport of a clay from one spot to another by natural agencies, it often happens—especially if the distance of transport be great—that the material becomes contaminated with various substances which it encounters in its journey. Moreover, in many cases old beds of clay have been washed away, and the product—mixed with other substances—re-deposited elsewhere in an exceedingly impure form. Of all the foreign bodies which thus find their way into clay, the most common is *silica*. The analyses of most clays reveal a larger proportion of silica than is to be found in pure kaolin, and the excess is probably present in a state of mechanical admixture. Sometimes, indeed, the free silica may be detected in the form of fine grains of sand disseminated through the mass of clay.

Since silica is exceedingly difficult of fusion, its presence in a free state renders the clay highly refractory, and is therefore of value in those materials which are required to resist heat. The most famous *fire-clay* in this country—that of Stourbridge, in Worcestershire—contains as much as 65 per cent. of silica, or nearly 20 per cent. more than is to be found in a pure kaolin. The Stourbridge clay occurs in the coal-measures, and its relation to the coal is worth a moment's notice. When the late Sir William Logan was engaged, forty years ago, in examining the South Wales coal-field, he was struck by the fact that each bed of coal rests upon a layer of hardened clay. This layer is known to miners as *under-clay*, *seat-earth*, or *coal-seat*, names which at once explain its connection with the overlying seams of coal. Fig. 2, Vol. I., p. 88, not only shows the position of the under-clay (*a*) beneath the coal (*b*), but also shows that this clay is penetrated by the roots of fossil plants. There can hence be no doubt that the under-clay represents the ancient soil which supported the forest of coal-forming plants, each bed of clay representing a fresh land-surface. The Stourbridge fire-clay is an under-clay of this nature.

The presence of free silica is of value in a clay, not only by rendering it refractory, but also by helping to diminish the shrinkage which the clay suffers when baked. To avoid the production of cracks consequent upon contraction, the brickmaker is in the habit of mixing sand with his clay, while the potter for a like reason incorporates ground flint with the finer clay upon which he operates. Many clays in their natural state contain sufficient admixture of sand to be used at once for brick-making, and are consequently known as *brick-earth*. Thus the upper part of the London clay, becoming sandy, passes into a brick-earth or loam.

The term *loam* is applied to all kinds of impure clay, but the principal impurity is generally sand. When a clay contains a good deal of carbonate of lime—which is a very common constituent of rocks, and is therefore likely enough to find its way into a clay—it is termed a *marl*. A marl is therefore a calcareous clay, while a loam is a sandy clay. Marls are often used in the manufacture of pottery, and in this case an additional source of contraction during firing is found in the expulsion of the carbonic acid from the carbonate of lime. In making yellow bricks from the brick-earths of the Thames Valley below London, it is common to add carbonate of lime in the form of ground chalk. Without the addition of this chalk, the clay would yield a reddish instead of a yellowish brick.

When a clay burns red, it may be taken as a sure sign that *iron* is present. The iron occurs generally in the form of oxide, with or without water, but sometimes as a carbonate, or even sulphide. If the clay in its natural state be red, the iron is present as that compound which is known to chemists variously as peroxide of iron, sesquioxide of iron, or ferric oxide. If the clay be yellowish or brown, the oxide present is combined with water, as hydrated peroxide of iron or ferric hydrate; but when the clay is burnt the water is expelled, and the oxide, thus reduced to the anhydrous condition, imparts a red colour to the clay. In bricks, tiles, and terra-cotta it is frequently desired to produce a full red colour, and hence iron-bearing clays are purposely employed. The beautiful Roman pottery, known commonly as Samian ware (Fig. 5) is so uniformly of a rich red tint, resembling sealing-wax, that the old potters must have mixed some kind of ochre with their clay. On the other hand, in the manufacture of most earthenware the presence of iron is extremely prejudicial, since it prevents the potter from producing a fine white body. Clays which are destitute of iron are therefore eagerly sought in the Potteries, and much of the value of the Dorset and Devon clays may be traced to their

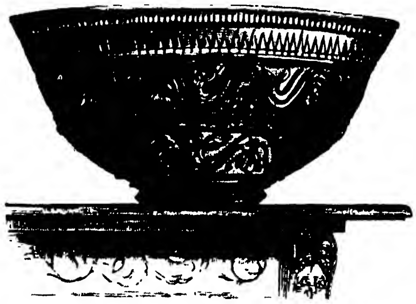

Fig. 5.—Specimen of Samian Ware (Roman Red Pottery).

comparative freedom from any ferruginous impurity.

While referring to the occurrence of iron in clays, some mention should be made of the remarkable deposit of very fine red clay which has been shown, by the explorers in the *Challenger* expedition, to cover vast areas in some of the deepest parts of the sea-bottom. It is believed by Mr. Murray that the greater part of this reddish mud has been produced by the decomposition of felspathic substances, such as pumice. In its origin, therefore, it resembles most other clays, while analysis shows that it also resembles them in composition. According to another view, which has been put forth on high authority, part at least of this red clay represents the insoluble residue left on the solution of multitudes of minute calcareous tests, or shells, belonging to the *foraminifera.**

It is worth while to note the resemblance of the latter view to that which has been advanced, with much ingenuity, to account for the origin of many of the finer clays found in this country. Mr. George Maw has suggested that many of our clays are merely the undissolved matter of limestone rocks, the greater part of the solid rock having been carried off by running water, while the insoluble impurities are left behind in an extremely fine state of division. Thus, the "pockets," or egg-cup-shaped cavities (*a*), in the mountain limestone (*b*), represented in Fig. 6, contain clay which may have been produced in this way. It has even been suggested that such an explanation may be extended to explain the origin of the pipe-clays and potter's clays of Bovey and Wareham. Instead of holding that these clays, as explained above, represent the decomposition of granitic rocks, it has been boldly argued that they are merely the insoluble impurities of the chalk—a rock which probably at one time spread in great thickness over the area in question, but which has been stripped off, or *denuded*, by geological agencies, leaving vast quantities of a fine clayey residuum.

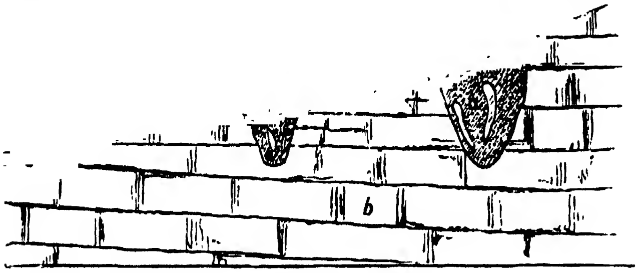

Fig. 6.—"Pockets" of Clay and Sand in Mountain Limestone, near Llandudno, North Wales.

Before leaving the subject of clay, it is well to state definitely what has before been mentioned incidentally, namely, that many beds of clay have undoubtedly been formed by the breaking-up and reconstruction of still older clays. The rocks known as "shales" and "slates" are nothing but beds of clayey mud which have been hardened and otherwise altered.† These rocks, which form a very considerable portion of the earth's crust, are constantly being disintegrated, or broken up, by the action of such destructive agencies as air and rain, frost and thaw, stream and wave. Ultimately the rocks are reduced to the state of a fine mud, consisting mainly of silicate of alumina, which may be carried off by running water to a considerable distance, and there redeposited as a new stratum of clay.

And thus it may happen that the clay which is being dropped particle by particle on the sea-bottom to-day has been derived from the destruction of some ancient clay, and this perhaps in turn from a clay of yet earlier date, until finally—if we could carry our inquiry far enough backward—we might trace it to the disintegration of some old granitic or other felspar-bearing rock. Such are the changes which may be read in the history of many a clod of clay. They are strange and various enough, but it will be seen that in all cases we trace the origin of the clay to the alteration of other kinds of *mineral* matter; and it need hardly be said that science knows nothing of the production of clay from *organic* sources, such as the poet refers to when he tells us that—

> "Imperious Cæsar, dead and turned to clay,
> Might stop a hole to keep the wind away."

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* "Science for All," Vol. I., p. 14.

† "Science for All," Vol. I., p. 342.

A HOUSE FLY.

By Arthur Hammond, F.L.S.

THE immense class of insects is divided by naturalists into a few great divisions called orders, which are distinguished from one another by the number and character of the wings of the insects which compose them. Thus we have seen * that the Cockroach belongs to the order *Orthoptera*, or straight-winged insects. So now if we look at a house fly we shall find that it belongs to the order *Diptera*, or two-winged insects, the hinder pair of wings being converted into two little organs like drum-sticks, called halteres or balancers. If we examine any specimen under a magnifying glass we shall find that like all other insects, the body is divided into three parts, the head, the thorax or breast, and the abdomen or belly, and each of these parts again consists of a certain number of rings or segments. This division of the body into segments is the great distinguishing feature of all those animals which Cuvier grouped together under the term Articulata. It is seen in the earthworm which consists of a number of similar rings following each other. Here, however, we find nothing like jointed limbs attached to the segments, but only a few very fine bristles with which the creature forces its way through the soil. The sea and sand worms are, however, more elaborately provided with fleshy tubercles, and a whole armoury of bristly weapons. The higher classes of articulate animals, such as centipedes, spiders, crabs, lobsters, and insects, are again distinguished by the possession of jointed legs, articulated to the body and replacing the simpler tubercles and bristles of the worms.

But, it may well be asked, how is it possible to regard so complex a creature as a crab, a beetle, or a fly as made up of a number of rings or segments? Indeed, on a superficial view it is difficult to realise that such is the case, and the difficulty arises from the fact that while the ringed type of structure in all of them is fundamentally the same, the modifications which it undergoes in each segment, are subject to endless diversity. Thus some of the rings may be enlarged to a comparatively enormous extent at the expense of those adjoining them. Some of them may be furnished with legs or wings, while others are destitute of these appendages, and two or more rings may be so welded together as to render their separate identification a matter of considerable difficulty. The more perfectly organised the body is—that is, the more the various actions and processes of life are carried out by organs *specially* adapted for their purpose—the more will its parts differ from one another, and the less uniformity of structure will it present. In the worm, the centipede, or the maggot of the very fly which forms the subject of this paper, each one of the similar segments of which its body is composed contributes a little to the act of locomotion, but in the perfect insects locomotion is effected much more perfectly by means of organs (the wings and legs) *specially* fitted for that purpose alone, and confined to one particular part of the body, namely, the thorax. The fly is a more highly-organised animal than the worm, the centipede, or the maggot, and its parts differ from one another, and the complexity of its structure is increased in corresponding proportion.

Insects are usually said to be composed of thirteen segments, viz., one for the head, three for the thorax, and nine for the abdomen. Inasmuch as the various appendages of the head, the jaws, antennæ, &c., are believed to be the limbs of originally distinct segments, there is much reason for considering the head as really composed of five segments instead of one, but we will prefer to regard it here as the first segment of the insect, and commence our description therewith.

We have seen that the cockroach is furnished with a pair of very long jointed organs called antennæ. Those of the fly are very differently formed, and are composed of six joints only. They lie in a hollow in the front of the head, and unless looked at carefully with a microscope it is probable that only the third and sixth joints will be discerned the first, second, fourth, and fifth being very minute (Fig. 2). The third joint is covered all over with a great number of little sacs extending inward from the surface, and covered with a fine membrane. Some have supposed that this joint is an organ of hearing, others of touch, and others of smelling. It is possible that insects may possess senses which we do not know, and of which therefore we cannot form an idea. The three last joints spring from near the base of the third, and not as usual from the end of it, and the sixth is furnished with a tuft of fine hairs.

Perhaps the most wonderful portion of the fly's structure is the mouth. The mouths of insects are of two kinds—the mandibulate, or biting mouth, of which we have had an example in the cockroach, and the suctorial mouth, or that adapted for suction, and of the latter there are many different forms; but whatever may be the form of the mouth it always consists of the same parts differently modified, though it does not follow that they are always present in their full complement. The mandibles and maxillæ which are so conspicuous in the mouth of the cockroach are absent from that of the fly, or, if present, are at least so difficult to recognise that we shall not notice them here. The mouth, therefore, consists of the following parts only—viz., the labrum, the labium, and the maxillary palpi, which are visible under ordinary circumstances. If, however, we watch the insect while feeding in the sugar-basin we shall see that these parts form collectively the terminal portion of a double-jointed or elbowed organ (Fig. 9), of which the basal portion, known as the pharynx, lies usually within the head, but can be extended at will, and the terminal joint being then straightened upon it, the two together form what is called the proboscis—an organ, indeed, not quite so big as that of the elephant, but quite as indispensable to its tiny possessor. As the mouth of the fly is of the suctorial kind, we shall find in the pharynx a most wonderful provision for causing the ascent of fluids from the mouth to the gullet, and so on to the stomach—in fact, this part forms a very perfect pump. The greater part of it is filled with muscles (Figs. *3a*, *3b*, *3c*), which by their contraction separate the walls of its cavity and thus cause a vacuum, into which the fluid aliment, moistened by the saliva, rushes. The muscles then relax and the pharynx closes upon its contents, which are thus passed on to the gullet.

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* "Science for All," Vol. III., p. 325.

The labrum (Fig. 5) forms the covering of the mouth from above. It is a small lancet-shaped piece, and lies in a groove on the upper surface of the enormously enlarged labium. It is provided at the base with two long processes which lie on either side the pharynx, and are connected thereto by muscles, by the action of which the proboscis can be straightened when in use.

The labium is a very complicated and beautiful organ. It consists of the mentum—a horny piece on the under side of the base of the terminal joint, the upper surface of which is hollowed into a groove to receive the labrum; from the base of this groove springs the tongue, a very fine horny lancet, which thus lies between the labium and the labrum. The labium is terminated by two large fleshy lobes constituting the ligula, as in the cockroach, only here the lobes have become the most important and striking feature in the mouth. They are each traversed by a series of channels excavated in the soft membranous integument and converging to two larger ones of a similar character, which again open into the groove of the labium. All these channels, which have received the names of false tracheæ, are kept open by a great number of horny rings, or rather half-rings (Fig. 10). In the blow-fly these half-rings are forked alternately at either end (Fig. 11), thus making the proboscis a very beautiful microscopic object. The end of all this complicated arrangement appears to be to facilitate the flow of fluid substances by capillary attraction towards the mouth.

The maxillary palpi (Fig. 5) are two club-shaped organs, springing from the membranous integument of the pharynx. Although the maxillæ are not seen in this insect they are found in some others, such as the gad-fly and the various kinds of hoverer flies, where they take the form of lancets, in common with the labrum and the tongue.

The eye of the fly is composed of a great number of similar parts, each of which serves the purpose of a separate eye but it is doubtful whether the faculty of vision is so perfect as in man and in those animals where one highly-finished organ supplies the place of all this multitude. Externally, the surface is divided into minute hexagonal areas, or facets, as they are called, about 2,000 to each eye, each of which is a double convex lens, the cornea of a separate eye, though sometimes the term cornea is applied collectively to the whole of them. Each facet (Fig. 12) has behind it a conical body surrounded by dark pigments, the apex abutting on a fibre of the optic nerve. A very pretty experiment may be made by placing a flattened portion of the cornea of the eye on the stage of a microscope, and then holding a small object such as the point of a knife between the stage and the mirror, when the image of the object will by careful adjustment be visible in each of the facets.

We will now pass to the second division of the body—the thorax (Figs. 1 and 14), in which the organs of locomotion are concentrated. The three segments of which it consists are known by the following terms—viz.: the pro-thorax, the meso-thorax, and the meta-thorax, which may be easily remembered as fore, middle, and hind thorax, such being the meaning of the Greek prefixes employed. Each bears a pair of legs, and in addition the meso thorax carries the wings and the meta-thorax the halteres. In the cockroach it was easy to separate the three segments from each other, but in the fly this is much more difficult, for although we are sure, from the existence of the three pairs of legs, that three segments are concerned, yet it will be found that they are so merged together into one compact mass that it is only by carefully comparing it with other insects, and by taking into account its internal muscular structure that we are able to know where one segment ends and another begins. It will suffice, therefore, here to state that as the wings are the most important organs carried by the thorax, and require large muscles to effect their movements, the segment to which they belong —viz., the meso-thorax, is greatly enlarged at the expense of the other two, almost the whole of the parts shown in the accompanying drawing of the thorax (Fig. 14) belonging to it. By a universal law of growth the enlargement of any one segment is always accompanied by a corresponding diminution in those adjoining it; thus the pro-thorax is reduced to a mere rim in front to which the fore-legs are attached, and of the meta-thorax scarcely anything remains but its appendages—the halteres and the hind-legs. In the meso-thorax of the fly may be seen all the parts of which an insect segment can consist—viz., a dorsal plate on the upper surface, a ventral plate on the lower surface, and two lateral or side-plates; also two pairs of appendages: an upper pair, the wings, and a lower pair, the legs (Fig. 15). The dorsal plate covers the whole surface of the back between the wings. The ventral and lateral pieces are scarcely less conspicuous. The former occurs between the fore and middle legs. In the pro-thorax the upper pair of appendages are wanting in the perfect insect, but exist as two button-shaped bosses on the back of the pupa (Fig. 21, *pa*). In the pupa of the gnat they are very conspicuous, and carry the breathing organs. In the meta-thorax the upper pair of appendages are found in the halteres, which are a kind of modified wing. Some have thought that they serve to balance the insect during flight like an acrobat's pole; it is probable, however, that they serve some other purpose beside, as organs of sense, for peculiar microscopic structures are found at their base, to which one of the largest nerves in the body proceeds.

The wings, like those of other insects, consist of a double membrane; they are in principle flattened bags or sacs, extensions of the skin—or integument, as it is called—of the thorax; they are strengthened by folds of the membrane called nervures, in which ramifications of the tracheæ or breathing tubes run. Both surfaces are covered with very minute hairs.

The legs consist of the same parts as those already enumerated in the cockroach. The tarsal joints are five in number and the last is furnished, in addition to the two claws which are found in all insects, with a delicate pad (Fig. 13) by means of which the fly is enabled to walk upon walls, ceilings, &c. The pad is furnished on its under surface with a great number of trumpet-shaped hairs (Fig. 13*a*), from the ends of which a viscid fluid is secreted, which causes the feet to adhere sufficiently to any surface to bear the insect's weight. Flies are frequently attacked with a kind of mould called *Empusa muscæ*, which eventually kills them, but before this happens they are rendered so weak by the progress of the disease thus caused that they cannot exert sufficient muscular force to detach their feet from the surface on which they rest, they become therefore glued to the spot, and die there. In the autumn, dead flies may frequently be seen thus fixed on windows, &c., the still spreading fungus forming a whitish patch around their bodies.

The rings of the abdomen are, as before stated, nine in number. Of these, the first five are very simple, consisting only of a dorsal and a ventral plate, with no appendages. It is in this portion of the body that the articulated structure is more easily seen. The dorsal plates are much larger than the ventral (Fig. 16) and occupy at least three-fourths of the circumference of each segment, the small ventral plates occupying a narrow space in the centre of the under surface. The four last segments constitute the reproductive organs.

Before we leave the external parts of the insect we must look at the spiracles, of which the most conspicuous are those of the thorax. They belong to the hinder portion of each segment, and there are two pairs of them, one belonging to the pro-thorax in front, and one to the meso-thorax behind. The meta-thorax has no spiracle. They are furnished with branching processes, projecting across the opening for the purpose of keeping out dust, &c. (Fig. 17). The spiracles of the abdomen are situated near the lower edges of the dorsal plates (Fig. 16), and are very small, requiring a microscope to reveal them; they are little round pores with a few hairs projecting across them (Fig. 7). The main tracheæ of the thorax extend from the anterior to the posterior spiracle on each side, and branch out in all directions between the great muscles,

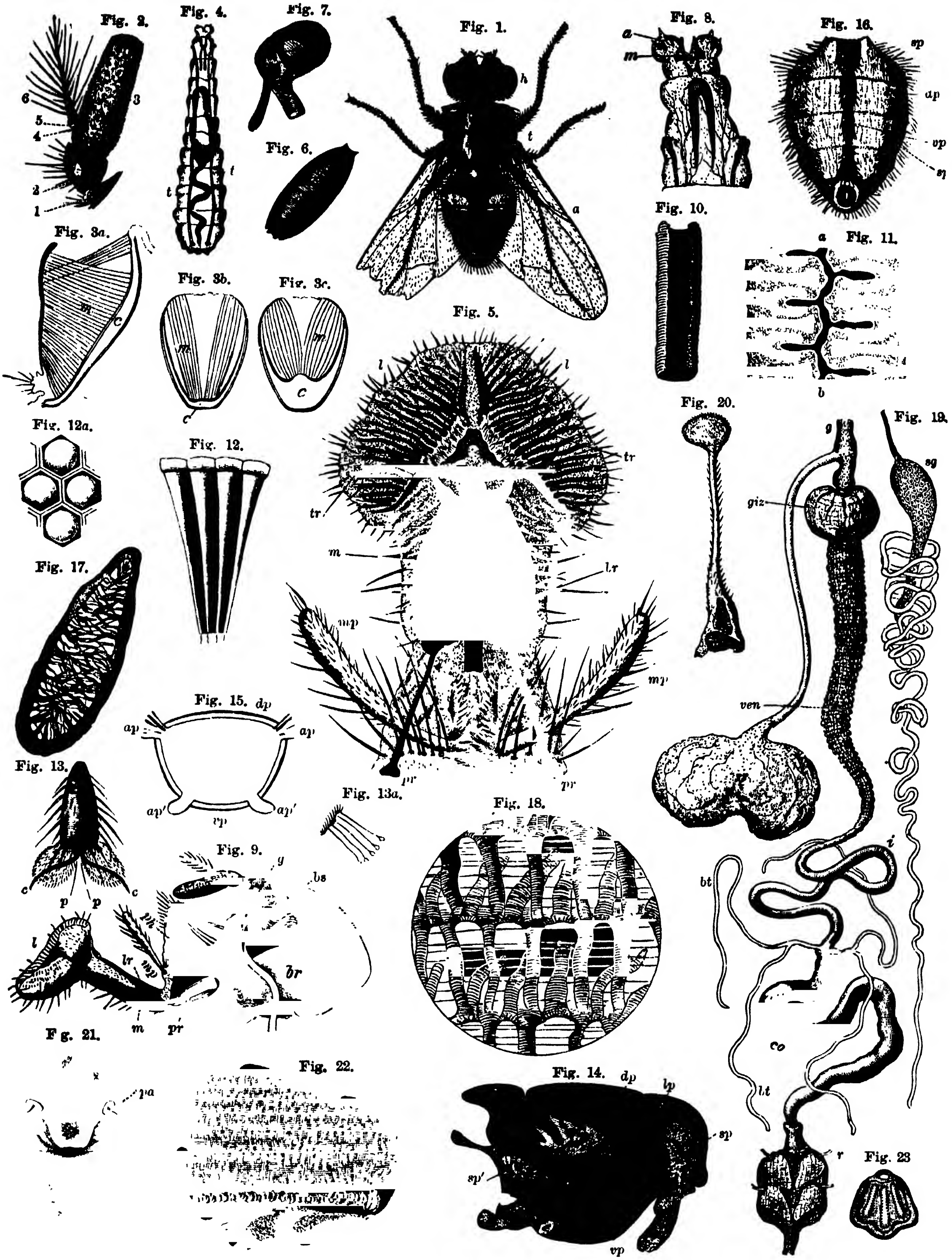
Fig. 2.
6
3
5
4
2
1
Fig. 4.
t
t
Fig. 7.
Fig. 6.
Fig. 1.
h
t
a
Fig. 8.
a
m
Fig. 16.
sp
ap
vp
sj
Fig. 3a.
m
c
Fig. 3b.
m
c
Fig. 3c.
m
c
Fig. 10.
a
Fig. 11.
b
Fig. 5.
l
l
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lr
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pr
pr
Fig. 12a.
Fig. 12.
Fig. 20.
g
Fig. 19.
sg
giz
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Fig. 17.
Fig. 15.
dp
ap
ap
ap'
ap'
vp
Fig. 13.
c
c
p
p
Fig. 13a.
Fig. 9.
g
bs
l
lr
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pr
Fig. 18.
i
bt
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F g. 21.
pa
Fig. 22.
Fig. 14.
dp
lp
sp
sp'
vp
Fig. 23

VARIOUS PARTS OF THE HOUSE FLY.

(Explanation of Figures will be found on p. 27.)

which occupy this part of the body, as may be seen in Fig. 18. From this a large branch passes into the head and another into the abdomen, at the base of which it swells out into two large sacs filled with air. The abdomen of the drone flies is frequently rendered almost translucent by the presence of these large air sacs.

The nervous system of the fly, as in the cockroach, consists of a series of ganglia connected by nerve cords. This type of structure is, however, greatly modified in the fly; the ganglia, which in most other insects are repeated at each segment, are here concentrated into two chief nerve centres, one in the head, and one in the thorax. That in the head, which may be called the brain, surrounds the gullet (Fig. 9) and sends nerves to the eyes, antennæ, mouth, &c. The nerves of the eyes are very large, and are called the optic nerves. A filament from them enters each of the cones of the eye. The nerve centre of the thorax supplies the muscles of this part of the body—a large branch goes to the halteres, and a long branching filament to the various organs of the abdomen. If a fly be preserved in spirits it will render the nerves hard, white, and easily traced.

The alimentary canal (Fig. 19) * commences with the pharynx, and passing through the brain enters the thorax, this portion forming the gullet. It then divides into two branches, one of which is continued as a fine tube into the abdomen, where it opens into a double sac, the crop. Into this the food first passes, and after remaining for a time is brought up again, and passes into the other branch to undergo digestion. The other branch opens at once into the gizzard, a globular cavity with thick walls which secretes the gastric juice. As the fly feeds upon fluid substances this organ is not provided with teeth like that of the cockroach. The gizzard is followed by the stomach or ventriculus, which occupies the whole length of the thorax, its surface is divided into little square pits by the longitudinal and circular muscular fibres which surround it. The tubes which open into the stomach of the cockroach are not present in the perfect fly, but there are four of them in the larva. The small intestine, or ileum, extends from the stomach to the opening of the bile tubes (or Malpighian glands), which are succeeded by the large intestine, or colon, and the rectum, as we have seen in the cockroach. The rectum of the fly is a pear-shaped cavity into which project four little glandular organs called the rectal papillæ. The salivary glands commence in the thorax as long convoluted narrow tubes, one on either side of the stomach, but their blind extremities extend into the abdomen. Each tube opens anteriorly into a little sac which communicates by a ringed duct with the base of the tongue. Their office is to secrete an acrid juice called the saliva. It is this which is poured into the wound and imparts its painful character to the bite of gnats and other insects. The bile tubes are long beaded tubes which unite together in pairs, to empty themselves by two large ducts into the intestine. A difference of opinion exists as to whether they answer to the liver or the kidneys of the higher animals.

The muscles of the fly are attached to the inner surface of the horny integument, which thus answers the purpose of a skeleton. They differ from those of the higher animals, chiefly in the fact that they are, at least many of them, attached directly to the integument at either end without the intervention of tendons, so that they are of equal diameter throughout. Like the nerves, they are rendered hard and white by the action of spirit. We shall have space only to notice the most important, which are those of the thorax (Fig. 22). This part of the body, with the exception of the narrow passage left for the stomach and salivary glands, is entirely filled with muscles. The two principal masses occur just under the dorsal plate, and extend longitudinally from end to end of the thorax. On either side of these, and separated from them by the main tracheæ, are other muscles which take a different direction passing from the dorsal to the ventral surface. By the action of these two sets of muscles, alterations are produced in the shape of the thorax resulting in the alternate elevation and depression of the wings during flight. These alterations and the consequent movements of the wings, may be produced artificially by taking a recently killed fly, and placing one blade of a pair of dissecting forceps behind, and the other in front of the upper part of the thorax, and alternately compressing and relaxing the forceps, when the wings will be seen to open and close as they do during flight.

As in all other insects, there are no blood-vessels in the fly, and the heart is represented by a slender pulsating tube called the dorsal vessel.

The larva or maggot of the fly is found in dung, but as that of the blow-fly found on meat is so much better known, we will conclude with a few words on it; the description of the one will apply

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* The parts of the alimentary canal should be compared with those of the Cockroach.

pretty well to the other. The body (Fig. 4) consists of thirteen segments, and is unprovided with feet, its movements being effected by the contraction of one segment upon another, aided by a pair of minute hooklets (Fig. 8), the mandibles, with which it tears its way through the festering mass in which it lives. Eyes there are none, for they are not required. A pair of fleshy globular organs well supplied with nerve cells, may represent either the antennæ or palpi. The alimentary canal is somewhat similar to that already described in the fly, except that the crop opens by a short neck into the gullet, instead of being connected thereto by a long tube, as in the fly. Two long silvery tubes, the main tracheæ, extend nearly the whole length of the body, and open by spiracles in the last segment. These spiracles are rather curious, a drawing (Fig. 23) of one is given among the woodcuts. When the time arrives for the insect to undergo its metamorphosis, the skin of the larva dies, turns first red and then almost black, and hardens into a barrel-shaped protective covering for the insect called the pupa case (Fig. 6). Within this a great change takes place, all the muscles and tissues of the maggot disappear, with the exception of the nervous centres, and are resolved into a semi-fluid matter from which those of the fly are formed anew within a delicate integument called the pupa skin. The pupa case or dead skin of the larva thus serves the same purpose as the silken cocoon spun by the silkworm, only the maggot has not the trouble of spinning it, and the enclosed pupa skin answers to the skin of the silkworm pupa (or chrysalis, as it is sometimes called) when it is removed from the cocoon. The legs and wings of the future insect are each enclosed in a separate prolongation of the pupa skin (Fig. 21) which remains behind as a delicate membrane in the pupa case after the escape of the insect from its prison. So great is the change that it is almost difficult to conceive that the maggot and the fly are one and the same being.

EXPLANATION OF FIGURES (See p. 25.).

Fig. 1.—House Fly: *h*, Head; *t*, Thorax: *a*, Abdomen.
Fig. 2.—Antenna: the numerals indicate the several joints.
Fig. 3*a*.—Pharynx, Longitudinal Section: *m*, Muscles; *c*, Cavity.
Fig. 3*b*.—Ditto, Transverse Section, closed, the Muscles being relaxed.
Fig. 3*c*.—Ditto open, the Muscles contracted.
Fig. 4.—Maggot of the Blow-Fly: *t t*, Main Tracheæ.
Fig. 5.—Mouth of the House-Fly: *lr*, Labrum; *m*, Mentum; *mp*, *mp*, Maxillary Palpi; *l*, *l*, Lobes; *tr*, *tr*, False Tracheæ; *pr*, *pr*, Processes of Labrum.
Fig. 6.—Pupa Case.
Fig. 7.—Abdominal Spiracle.
Fig. 8.—Head of Maggot of Blow-Fly: *m*, Mandible; *a*, Antenna.
Fig. 9.—Section of Head of House-Fly, showing *ph*, Pharynx; *g*, Gullet passing through; *br*, Brain; *fs*, Frontal Sac. The parts of the Mouth as in Fig. 5.
Fig. 10.—False Tracheæ of House Fly.
Fig. 11.—False Tracheæ of Blow-Fly, showing the Open Front of the Tube and the Forked and Straight Ends of the Rings.
Fig. 12.—Cornea and Cones of Eye in Section.
Fig. 12*a*.—Facets of Eye.
Fig. 13.—Foot of House-Fly: *cc*, the Claws; *pp*, the Pads.
Fig. 13*a*.—Hairs of Pad.
Fig. 14.—Side View of Thorax of Blow Fly; *dp*, the Dorsal Plate; *lp*, Lateral Plate; *vp*, Ventral Plate; *sp*, *sp′*, Spiracles of Pro- and Meso-thorax; the Pro-thorax and Meta-thorax are distinguished by dotted shading, all the central portion being Meso-thoracic.
Fig. 15.—Ideal Section of an Insect Segment: *ap*, *ap*, Superior, *ap′*, *ap′*, Inferior Appendages; Dorsal, Ventral, and Lateral Plates as before.
Fig. 16.—Under Surface of Abdomen of House-Fly: *sp*, *sp*, Spiracles; Dorsal and Ventral Plates as before.
Fig. 17.—Pro-thoracic Spiracle.
Fig. 18.—Tracheæ ramifying through Muscles of Thorax.
Fig. 19.—Alimentary Canal: *g*, Gullet; *giz*, Gizzard; *ss*, Sucking Stomach; *ven*, Ventriculus; *sg*, Salivary Gland; *i*, Ileum; *co*, Colon; *r*, Rectum with its Papillæ.
Fig. 20.—Haltere.
Fig. 21.—Pupa of Blow-Fly: *pa*, Pro-thoracic Appendage.
Fig. 22.—Section of Thorax of Blow-Fly, showing, *m*, Longitudinal Muscles of Flight.
Fig. 23.—Spiracle of Larva of Blow-Fly.

METEORIC STONES.

By G. F. Rodwell, F.R.A.S., F.C.S.,

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A METEORIC stone is one of those "uncommon objects of the country" which the casual student need hardly expect to come across in the course of a lifetime. However, the name sometimes occurs in the newspapers, and a visit to any considerable collection of natural objects cannot fail to bring those anxious for their nearer acquaintance into visual communication, at least, with a greater or less number of these objects. In the British Museum, for example, there are at present about 339 specimens gathered from many parts of the world (Fig. 1). On consulting Professor Maskelyne's catalogue it will be found that certain curious-looking nodules of an iron-like substance are styled "meteorites." A meteorite is literally that which is raised aloft in the air, and the term was formerly applied much more generally than now. Thus, any transitory phenomenon taking place in the atmosphere was called a meteor. There were aërial meteors, such as winds; aqueous meteors, such as rain, snow, and fog; meteors depending on the refraction of light, such as the rainbow, mirage, and parhelia; and luminous meteors, such as shooting stars, lightning, and the aurora borealis, nearly all of which have been already discussed. Although the term *meteor* is now commonly restricted to shooting stars,* the science of meteorology, which, as used by the ancients, and in accordance with its etymology, once embraced all the appearances of the heavens, still includes the phenomena which determine weather, seasons, and climate.

Meteoric stones, or meteorites, are solid masses which fall to the earth from the regions of space, and which often appear to form the nucleus of shooting stars. The meteoric stones in the British Museum are arranged into:—(1) Aërolites, or air stones, which are stony masses consisting of various silicates similar to those found in terrestrial rocks, interspersed with isolated particles of nickeliferous iron and troilite (protosulphide of iron). Of these the museum possesses 211 specimens, the largest of which weighs one hundred and thirty-four pounds. (2) Aërosiderites, or simply Siderites, masses of native iron, usually nickeliferous, and containing phosphides of nickel and iron, troilite, and sometimes carbon. Of these the museum possesses 114 specimens, the largest of which weighs more than three and a half tons (8,200 pounds). (3) Siderolites, which are meteorites consisting of porous or sponge-like masses of nickeliferous iron containing in cavities various silicates, such as are found in aërolites. Thus siderolites partake of the character of both aërolites and siderites. The museum possesses twelve such specimens, the largest single stone weighing nearly sixteen pounds.

Many well authenticated records of the fall of meteorites exist. The usual accompaniments are loud reports like thunder; the sky appears darkened and much disturbed, and the meteorite moves forward sometimes as a dark, dusky cloud, and sometimes surrounded by a dazzling luminous haze. At times a vast fire-ball sails through the sky, leaving behind it a long fiery track; then the mass explodes with a detonation like that of a thousand cannon, and numbers of meteoric stones are projected with a great velocity to the earth. Sometimes they sink to a depth of several feet into the soil. They are usually hot if dug up immediately, and some large stones are said to have remained hot for several hours after reaching the earth. From the fact of their sinking into the soil they are frequently discovered long after their fall, and under such circumstances, if they are iron meteorites, the surface is usually considerably rusted and weathered. However much this may complicate the examination of the surface, it is always easy to recognise a meteorite by its internal structure, and by chemical analysis. Its composition differs from that of terrestrial rocks; metallic iron is extremely rare in nature except in meteorites, and the iron-nickel alloy, usually containing about ninety per cent. of iron to ten per cent. of nickel, is exclusively meteoric.

Ancient records of the fall of meteoric stones are abundant. They are mentioned in a fragment of Sanchoniathon, by Damascius, and by Aristodemus. Livy mentions a fall of stones which took place on the Alban Mount in the reign of Tullus Hostilius, and Pliny asserts that a large stone fell near Ægospotamos, in Thrace, in the second year of the 78 Olympiad. A large mass weighing 255 pounds fell in Ensisheim, near Basle, on the 7th of November, 1492, and a portion of it is suspended by a chain near the door of the church. Cardan asserts that more than a thousand stones fell from the clouds in 1510 near Milan; and Gassendi affirms that he saw a flaming stone, apparently of four feet in diameter, fall on an eminence situated between the towns of Perne and Guillaumes, in Provence. When picked up it was found to be of a dark metallic colour, and very hard. It weighed fifty-nine pounds. A very perfect description of a meteoric stone is given by Mr. Howard. In December, 1798, the inhabitants of Benares observed a large fire-ball passing across the heavens; presently it exploded with a loud noise, scattering a number of stones. "Of these stones," says Mr. Howard, "I have seen eight nearly perfect: externally they were covered with a hard black coat, or incrustation, which in some parts had the appearance of varnish or bitumen; and on most of them were fractures, which, from their being covered with a matter similar to that of the coat, seemed to have been made in the fall by the stones striking against each other, and to have passed through some medium—probably an intense heat—previous to their reaching the earth. Internally they consisted of a number of small spherical bodies of a slate colour, imbedded in a whitish gritty substance, interspersed with bright shining spiculæ, of a metallic or pyritical nature. The spherical bodies were much harder than the rest of the stone; the white gritty part readily crumbled on being rubbed with a hard body; and on being broken a quantity attached itself to the magnet, but more particularly the outside crust or coat, which appeared almost wholly attractable by it."

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* "Shooting Stars," "Science for All," Vol. II., p. 144.

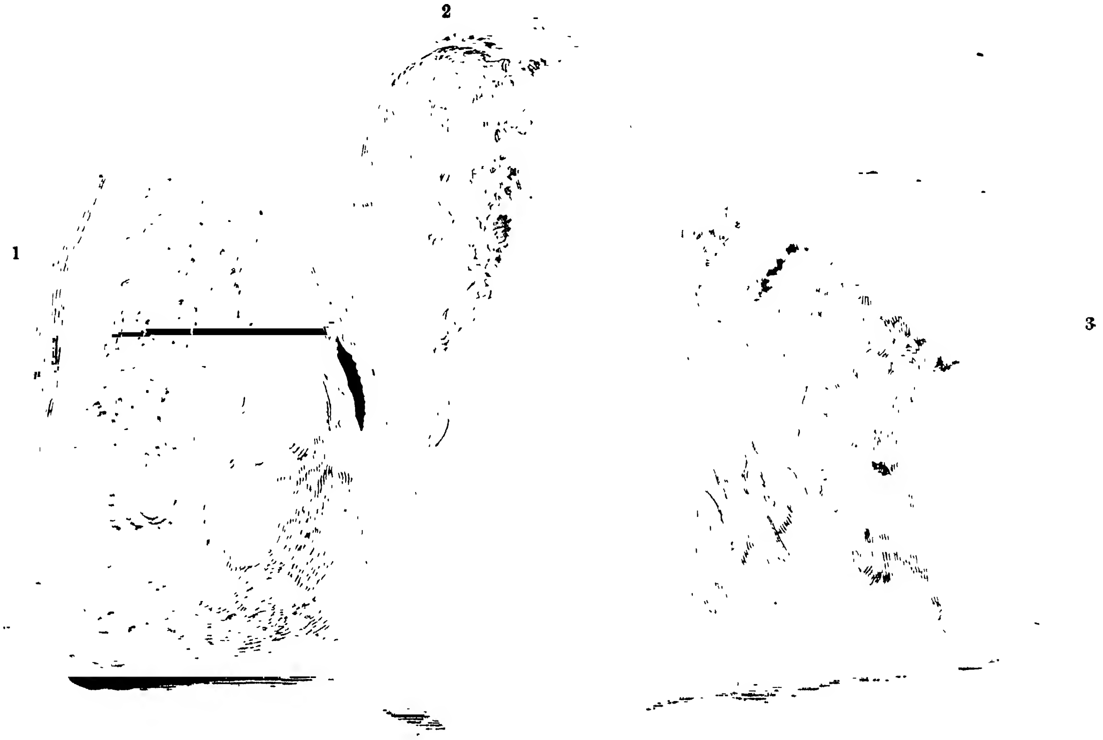

Fig. 1.—**Meteoric Stones.** (*From specimens in the British Museum.*)

1, From New Concord, Muskingum Co., Ohio, U.S.A. Fell May 1, 1860. One fragment of several thousand. About 10½ inches high. 2, From Qutahar Bazaar, Butsura, Sarun, India. Fell May 12, 1861. Fragment. About 13 inches high. 3, From Wold Cottage, Thwing, Yorkshire. Fell Dec. 13, 1795. About 9 inches high.

In 1776, Dr. Pallas, a Russian naturalist, found a mass of nickeliferous iron, weighing 1,400 pounds, near the summit of a mountain in Siberia. It was a siderolite, mainly made up of nickeliferous iron, the cavities of which were filled with olivine. The iron was very malleable, with a fine grain, a shining silvery lustre, and a specific gravity of 7·84. The inhabitants of the district had a tradition that this mass was seen to fall from the clouds. A few years later a great number of aërolites fell near Sienna. Dr. Phipson, in his work on Meteors, Aërolites, and Falling Stars, has pointed out that the year 1857 was rather remarkable for the frequency of the meteoric falls. On February 28th, an immense aërolite fell with a thundering crash about noon, at Parnallee, in the Madras Presidency. On collision with the earth it split up into numerous fragments, one of which, weighing 134 pounds, is in the British Museum. A little later in the year, aërolites fell at Stavropol, north of the Caucasus; and at San José, in Costa Rica. On April 15th, a peasant of Kaba, in Hungary who was asleep in the open air, was awakened by a report as of thunder. He saw at the same time a brilliantly luminous globe of fire, which shot across the sky and disappeared. Next morning an aërolite shaped like a loaf of bread was found near the village. It was analysed by Wöhler, and found to contain iron, nickel, olivine, and a carbonaceous substance of the nature of paraffin. In the following October a great fall of aërolites took place in the Commune des Ormes, in Yonne. Loud detonations were heard in the air, a globe of fire of large diameter was seen to move towards the earth, and presently a shower of stones descended, one of which passed near the head of a mason who was standing on a ladder. He descended at once, and found the stone sunk into the ground to a depth of about half a foot.

A remarkable meteorite fell in the Arrondissement of Casâle, in Piedmont, on the 29th of February, 1868. At half-past ten in the morning loud detonations, similar to discharges of artillery, were heard, followed by noises resembling the explosion of a mine. These were heard twenty miles off, at Alexandria. The sounds had scarcely died away when an irregular mass resembling a small dark cloud appeared at a great distance above the earth, enveloped in what appeared to be a cloud and leaving behind it a long train of smoke. Then a number of aërolites fell to the ground, the largest of which weighed nearly fifteen pounds, while two other pieces of less weight were found each about two miles distant. Flammarion states that in the Island of Lanaià-Uamai there is an aërolite six yards in diameter imbedded in the ground, which fell at the beginning of this century, and which has resisted all attempts to raise it to the surface.

The Swedish Arctic expedition brought back some very remarkable meteorites in 1870. They were discovered lying loose on the shore in Greenland, and immediately resting on basaltic rocks of Miocene age, in which they were probably originally embedded. Some of the masses of native iron were found to enclose fragments of basalt, while iron of the same composition as that of the meteorites was found disseminated through the basalt. The composition of these masses of iron being quite different from that of any terrestrial rock, Baron Nordenskjöld regards them as meteoric, and he believes that the fall took place over an area of two hundred square miles. The iron is nearly free from silicates, but it contains sulphide of iron, and a good deal of occluded gas, also five per cent. of nickel, and from one to two per cent. of carbon. The largest mass weighs twenty-one tons, and its maximum sectional area is about forty-two square feet. But most geologists are of opinion that these masses are of telluric origin, and that they were, possibly, projected by volcanoes in early stages of the earth's history.*

A considerable addition to our knowledge of meteorites was obtained in 1876, when an aërolite fell at Ställdalen, in Sweden, at 11.50 A.M. on June 28th. The fire-ball from which it descended was visible over a large portion of middle Sweden, and it appeared as a large pear-shaped mass, which seen from some localities was of blinding whiteness, from others of a fiery red. From some points of view it resembled a luminous streak of violet light, from others the streak appeared white, and reddish-white, or light grey. In size the fire-ball equalled that of the full moon, and when it burst a white smoke remained. The meteor emanated from a point in Cephei, and it became luminous at a distance of 250 miles above the earth. Its diameter has been estimated at 1,500 feet. It is remarkable that it was not visible at the point where the meteoric stones fell, probably on account of the small cloud of absorbed matter collected in front of it; but loud detonations were heard, as also rumbling and rattling noises. The stones did not fall with a great velocity; one of them, weighing eighteen pounds, made a hole in the earth only eight inches deep. Many were seen to fall. The largest weighed nearly thirty pounds; but the total number of stones found was only eleven, weighing in all a little more than seventy pounds. They were distributed over an oval space a mile and a quarter broad by five miles long. They presented on being broken a coarse breccia-like appearance, and on analysis were proved to consist of nickeliferous iron, olivine, bronzite (silicate of magnesia), sulphide of iron, small traces of phosphide of iron and of nickel, and of a phosphate and chloride of iron.

To take a final example—the Rowton Siderite—and one which is of special interest to us both because it fell in our own country, and because the fall of an iron meteorite is so rarely witnessed, that out of the 114 specimens in the British Museum, only seven were seen to fall. The following account of this meteorite is taken from a local newspaper †:—

"An addition of exceptional interest has recently been made to the collection of meteorites in the British Museum, by the presentation, on the part of the Duke of Cleveland, of a siderite (iron meteorite) which fell on his Grace's property at Rowton, near Wellington, in Shropshire, about seven miles north of the Wrekin, on the 20th of April last. At about twenty minutes to four o'clock on the day mentioned, a strange rumbling noise was heard in the atmosphere, followed almost instantaneously by a startling explosion resembling a discharge of heavy artillery. There was neither lightning nor thunder, but rain was falling heavily, the sky being obscured by dark clouds for some time both before and after the incident narrated. About an hour after the explosion, Mr. George Brooks, stepson of Mr. Bayley, had occasion to go to a turf-field, in his occupation, adjoining the Wellington and Market-Drayton Railway, about a mile north of the Wrekin, when his attention was attracted to a hole cut in the ground. Probing the opening with a stick, Mr. Brooks discovered a lump of metal of irregular shape, which proved to be a meteorite weighing seven pounds and three-quarters. It had penetrated to a depth of eighteen inches, passing through four inches of soil, and fourteen inches of solid clay, down to the gravel—conclusive evidence of the force of its impact with the earth. The hole (which has been protected for further investigation) is nearly perpendicular, and the stone appears to have fallen in a south-easterly direction. Some men were at work at the time within a short distance, and they, together with many other people in the neighbourhood, heard the noise of the explosion."

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* Rink: "Danish Greenland." Edited by Robert Brown. Pages 81, 82.

† *The Wolverhampton Chronicle*, April 24th, 1876.

The siderite, when found by Mr. Brooks, was warm; the surface was black, but where it had come into collision with the earth, the surface-crust was rubbed off, and the metallic character of the mass revealed. The outer crust, on being examined at the British Museum, was found to consist of magnetic oxide of iron; where this was rubbed off, a bright surface of nickeliferous iron was discovered. Deep fissures penetrated into the mass, and, undoubtedly, much of its substance was rubbed off by its friction with the atmosphere. In the account which Professor Maskelyne has given of this meteorite, he states that out of the whole collection of aërolites in the British Museum, only eight have fallen on the British Islands, while the Rowton meteorite is only the second siderite which is known to have fallen in Great Britain.

From time to time fine dust, having the same composition as certain meteorites, has fallen upon the earth.* Concerning this, Arago observes: "L'observation attentive des chûtes des poussières fait presumer qu'elles ne different pas essentiellement des chûtes d'aérolithes ordinaires." A remarkable exemplification of this has recently been observed by Professor Silvestri, of Catania. Not only did Silvestri find metallic iron in this extra-terrestrial dust, but also nickel and various silicates and phosphates. Whether this dust has been abraded from meteorites, or whether it circulates in space, and is attracted to the earth when it penetrates our atmosphere, we cannot tell, but there is no doubt that it is of cosmical origin. (Fig. 2).

We are led from the contemplation of the phenomena which accompany the fall of meteoric dust and stone, to discuss their origin; and concerning this there are wide differences of opinion, which, however, resolve themselves into two main theories.

On the one hand, Professor H. A. Newton, of Yale College, asserts that they are the same as shooting stars; that every shooting star must be a solid body; and that both periodic and sporadic meteors are solid fragments of certain known or unknown comets, coming into our atmosphere. Meteoroids are small fragments of such comets, fire-balls large fragments. In the majority of cases the meteorite does not reach the earth, because it is dissipated by the intense heat generated by its friction with the atmosphere before reaching the earth. In fact, meteors have often been observed to appear as luminous masses at some sixty or seventy miles above the earth's surface, and to disappear at from five to ten, leaving behind them a luminous track of abraded and ignited dust. Meteors must be solid bodies, because they often break up into numerous pieces, and they move in curved courses, while we cannot possibly imagine a gaseous or liquid body as existing permanently in the solar system. Again, the stone-producing meteors have the same varieties of colour, leave similar luminous trains behind them, move with the same velocities, and appear at similar heights above the earth's surface, as those which do not project meteorites to the earth.

On the other hand, Sir Robert Ball, Mr. L. Smith, Dr. Phipson, M. Tschermak, and others, consider that meteorites have had a volcanic source on some celestial body—probably the earth itself. They found this opinion on the fact that meteorites are always angular fragments, as if torn from some parent mass, before they reach the earth; that they often present similarities of structure to that of volcanic tufas, and that iron meteorites have a crystalline structure, which requires a long period of formation, in a nearly constant temperature, and which could, therefore, only be accomplished in the case of large masses.

M. Tschermak, after rejecting as untenable the connection of meteorites with shooting stars, contends that many celestial bodies may be able to project masses from their volcanoes which do not return by the force of gravity. Professor Ball argues that the sun cannot be the celestial body in question, because meteorites have the appearance of having been torn from rocks which were nearly, if not quite, solid—a supposition which the high temperature of the sun renders impossible; and again, although it is true that its projectile force is enormous, so also is its attraction of gravitation. Then, as to the moon, the mass of this planet is small, and it would not require a great amount of explosive energy to project a body beyond its sphere of attraction, and the projectile would fall upon the earth if its distance from the earth's centre when in perigee were less than the radius of the earth; but it must be noted that if the projectile escaped the earth *once* it would never fall upon it. Hence, the question of whether meteorites can come from the moon reduces itself into the question whether the lunar volcanoes are now active; and it is generally admitted that no appreciable volcanic action is now taking place at the moon's surface. In regard to the minor planets, a vast projectile force would be requisite, and it has been calculated that only one meteorite in 50,000 would fall upon the earth.

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* "Science for All," Vol. II., p. 149.

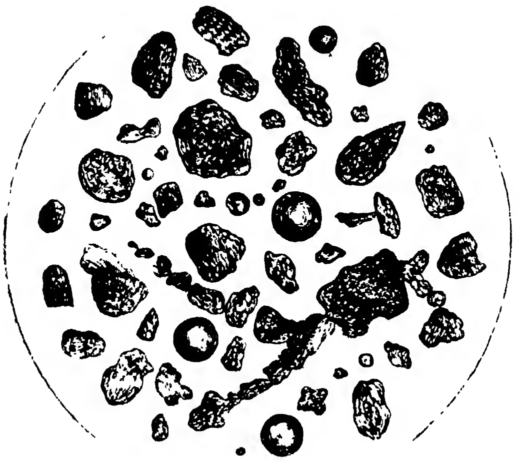

Fig. 2. Cosmic Dust (*After Silvestri.*)

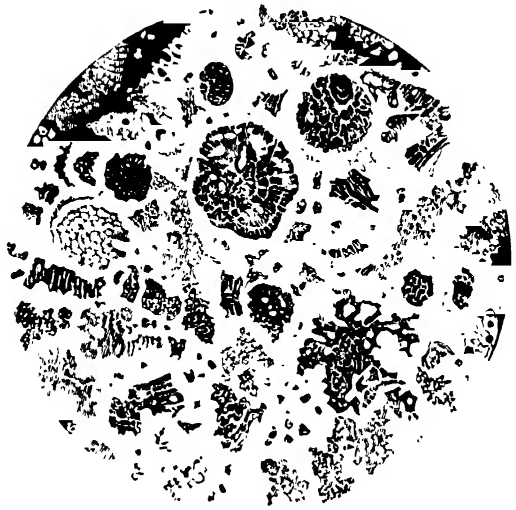

Fig. 3.—Microscopic Section of Meteoric Stone.

But that meteorites were projected from the earth in earlier stages of its history, when its volcanic force was more intense, seems more probable. It is true that an initial velocity of six miles a second would be required; but every projectile would, after accomplishing an elliptic orbit round the sun, pass through the track of the earth, and at every subsequent revolution it would pass through the same point. Thus, according to Professor Ball and others, the earth, whenever she receives a meteorite, is gathering back to her bosom the fragments launched into space in an earlier period of her history.

M. Stanislas Meunier, in the examination of three meteorites. one of which fell in Chili, one at Caille, in the Maritime Alps, and the third at Sétif, in Algeria, has discovered a curious relationship between them. He finds that the Chili meteorite is a mixture of two rocks; and that it is composed of iron identical with that of Caille injected into a stone, which is identical with that of Sétif. Thence he concludes that the iron is an eruptive rock, and he believes that he has proved the Caille iron and the Sétif stone to have been mutually connected by stratification upon an unknown planet. Formerly siderites fell, now aërolites fall. During the last 118 years only three falls of iron meteorites have been recorded, while three stony meteorites fall every year. Perhaps even a new kind is beginning to fall, for carbonaceous meteorites were unknown before 1803, and four have been since observed. M. Meunier believes that meteorites are the fragments of heavenly bodies which once revolved round the earth or the moon. These, in virtue of their small volume, have come to ruin much sooner than the moon, and their fragments have arranged themselves according to their density in concentric zones around the focus of attraction, towards which they are constantly impelled. The masses nearest the centre were of iron, and they were the first to fall, then came the stones of less density. Hereafter will, perhaps, arrive crystalline rocks, and then stratified formations. These views were combated by Professor Maskelyne, and rejected, and the counter arguments urged by M. Meunier are not, we must confess, very convincing. At all events, we think that the subject is not yet fit for such speculative treatment.

Professor John Le Conte, proceeding from the statement made by Nordenskjöld, that during the shower of meteoric stones which fell near Hessle, in Sweden, on January 1st, 1869, masses weighing two pounds, which fell on the ice, failed to penetrate more than three or four inches, and rebounded, shows that the small velocity thus indicated must be due to the resistance which the meteorite experiences on entering the atmosphere. He calculates that the maximum velocity attained by a cubical stone weighing two pounds, and having a specific gravity of three, is 159 feet per second, only *one-tenth* of the initial velocity of a rifle bullet. Its penetrating power would only be one-hundredth part as great as that of a mass of similar dimensions moving with the velocity of a rifle bullet. If the two-pound mass of stone were spherical instead of cubical, it would, under similar conditions, strike the earth with a velocity of 197 feet per second; and with larger meteorites the velocity would enormously increase. In fact, meteors have been observed moving with velocities included between fourteen and forty miles per second.

We have now to enquire what is the composition of meteoric stones. No new element has ever been found in them, but no less than twenty-four of the existing elements:—

Hydrogen
Lithium
Sodium
Potassium
Magnesium
Calcium
Aluminium
Titanium
Chromium
Manganese
Iron
Nickel
Cobalt
Copper
Tin
Antimony
Arsenic
Vanadium
Phosphorus
Sulphur
Oxygen
Silicon
Carbon
Chlorine.

The elements in italics have been found in the sun, together with a few others which have not yet been found in meteorites.

The rocks to which meteorites bear the nearest resemblance as regards mechanical structure, are certain volcanic bombs and tufas. We have before described the general composition of the three classes of meteorites. A convenient method of examination as to the proximate constituents of such bodies is afforded by the microscopic examination of their transparent slices (Fig. 3). They are then often seen to be crystalline throughout; at other times they consist almost entirely of spherules and granules. The mineral constituents of meteorites have been tabulated as follows by Professor Maskelyne:—

The *elements* are—*Iron with nickel,* containing traces of cobalt and copper; in some and probably in all cases with hydrogen, carbonic oxide, or other gases occluded in the metal; *Carbon* (both as graphite, and in combination with iron); *Sulphur.*

The *compounds* are—*Troilite,** or protosulphide of iron; Magnetic iron pyrites; *Magnesium sulphide; Oldhamite, or sulphide of calcium; Osbornite,* a double sulphide of titanium and calcium; Magnetite, or magnetic oxide of iron; Chromite, or chromate of iron; Silica; Oxide of tin. The following silicates:—Olivine, a silicate of magnesia and protoxide of iron; Enstatite, a silicate of magnesia; Bronzite, a silicate of magnesia and protoxide of iron; Augite (in several varieties), a silicate of magnesia and lime; Anorthite, a silicate of alumina and lime; Labradorite, a silicate of alumina, lime, and soda; Schreibersite (in several varieties), phosphides of iron and nickel; Hydrocarbons, not yet sufficiently investigated.†

The Pallas siderite, already mentioned (p. 29), shows the following composition:—Iron, 88·04; nickel, 10·73; cobalt, 0·41; manganese, 0·13; copper, 0·07; magnesium, 0·05; carbon, 0·04; in addition to a residue of iron, nickel, phosphorus, and magnesium, insoluble in hydrochloric acid, and a trace of sulphur and

Although much remains to be discovered regarding the composition of meteoric stones, we may probably with safety assert that they have been formed under conditions in which neither water nor free oxygen gas was present.

Various specimens of meteoric iron, if polished and then etched with an acid, exhibit peculiar crystalline markings, known as "Widmanstädtean Figures." Berzelius considered that they were due to an alloy of iron and nickel disseminated through the mass, which is less soluble than the surrounding matrix, but it is more probably due to the insoluble residue of Schreibersite or phosphide of iron and nickel, which remains after treating the siderite with hydrochloric acid. It may be added that many iron meteorites when ignited in a vacuum give off hydrogen as if they had cooled in an atmosphere of that gas, and "occluded" it at the moment of solidification. As hydrogen has been detected in the sun and some of the nebulæ, this supposition is not extravagant.

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* The minerals printed in italics are new to mineralogy.

† It is unnecessary to tabulate analyses of meteoric stones, as these have been fully given by various writers. The one given may suffice as a specimen of their composition.

WHY LIGHTNING IS SEEN AS A FLASH AND HEARD AS THUNDER.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.

It has been shown in a recent paper* that lightning is kindled in the thunderstorm by raising tracks of material substance scattered along its path into a state of sparkling incandescence, and that it is in this particular identical in nature with the ordinary electrical spark. The light, however, which strikes in either case upon the eye endures for an almost inconceivably brief interval of time. As a matter of fact the duration of the spark which issues from the prime conductor of an electrical machine does not exceed the millionth part of a second. But very delicate and complicated experiments have had to be devised to prove that such is the case, because when a quite instantaneous impression of light has been made upon the human eye, the effect remains as a vital sensation for something like the fifth part of a second after the illuminating impulse has ceased. It is for this reason that a burning stick whirled round in the dark presents itself to the eye as a continuous circle of fire. If the stick is made to circle round so quickly that it returns back to the same position in the circle five times every second, the impression of each successive luminous impulse originating in that part is produced upon the eye before the immediately preceding impression has died away. The light of the most intense flash of lightning probably does not last more than the thousandth part of a second. The length of the track through which lightning flashes in the air is sometimes surprisingly great. M. d'Abbadie measured lightnings in Abyssinia which were four miles long from the place where they issued from the cloud to the point where they struck the earth. M. Petit, another very trustworthy authority, marked the extent of a lightning discharge at Toulouse which proved to be more than ten miles long. In these cases, however, it seems as if the lightning passed along a track in which it was able to avail itself of intermediate stepping-stones of conducting substance by the way. Some electricians, indeed, attribute the zigzag form of forked lightning to this cause. They conceive that there are concentrated foci of condensed vapour, or other conducting substance, so scattered along the path that the electrical discharge is inclined to leap from the one to the other as it traverses its devious track. M. Dumoncel planned some very ingenious experiments which seemed to demonstrate that the forked discharge may be artificially produced. A miniature discharge, very nearly indeed resembling the forked lightning of the sky, is brought about when an electric spark is passed along the surface of a pane of glass which has been coated with aventurine—that is, a form of quartz in which spangles of metallic substance are intermingled with the siliceous matrix. Lightning of this class, however, issues only from very densely packed clouds, in which the nebulous flocculi lie in such close propinquity that the charged mass approaches to the condition of a continuous conductor. The resistance of the surrounding air then contributes materially to the result because it prevents the electrical charge from accomplishing its escape until it has acquired a very powerful expansive tension. The density of the air on this account has much to do with the intensity and brilliancy of the lightning. The most terrific storms, for this reason, are met with in low-lying regions and over plains. The mountain lightnings, although of frequent occurrence, are feeble in their intensity in comparison with those which are exhibited in denser regions of the atmosphere. This peculiarity is very beautifully shown by artificially varying the density of the air through which ordinary electrical sparks are allowed to pass. When the spark traverses dense dry air the luminous track assumes the appearance of a compact and compressed line of brilliant fire. But if the sparks are made to traverse the interior cavity of closed glass tubes, in which the air can be rendered rare by the action of the air-pump, the luminous track becomes wider and less brilliant as the rarity of the air is increased, until at last the well-known effect of the vacuum tube is produced, in which the discharge presents itself as a faint luminosity filling up the whole interior space of the tube, instead of as a bright shining line. There must, however, be a certain density of the air or gas remaining in the tube, or no discharge at all can pass. By the employment of the Sprengel air-pump, in which the vacuum is produced by falling mercury, the exhaustion of the interior of glass tubes can be carried so far that no discharge of a luminous kind can be brought about. This is one of the most telling proofs yet furnished of the fact that the electrical spark and glow are matter in a state of shining incandescence. Where there is no matter to shine, no light can be developed. The incapability of an electrical discharge to pass through void space is also interestingly illustrated by the circumstance that if a gold-leaf electrometer, with its leaves divergent under an electrical charge, is placed in an exhausted receiver of an air-pump, the divergence of the strips is maintained as long as the receiver remains deprived of its air.

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* "Science for All," Vol. III., p. 374.

Lightning passes along its extended track virtually in an instant of time. The speed with which electrical force is transmitted along its path varies with the resistance which it has to overcome in each particular case. But in the passage of lightning through the air this seems to approach very nearly indeed to the rate at which light travels through interstellar space, or 186,000 miles per second. The appearance of the progressive movement of lightning through the air is simply an illusion of the senses. It travels along a track of eight or ten miles with a speed which it is quite impossible for any human organ of vision to follow. It is practically everywhere in such a path at once, and is therefore seen instantaneously everywhere by the eye. The notion that lightning can be seen to strike either from the clouds to the earth, or from the earth to the clouds, is entirely without foundation in fact. The electric spark travels with such exceeding speed that it passes through gunpowder without causing it to explode, unless some plan is adopted for retarding its pace as it traverses the explosive grains.

The colour of lightning is altogether due to the nature of the substance which is made incandescent in its track. The blue, red, purple, or silver tints which are ordinarily much more brilliantly marked in warm climates and inter-tropical countries than they ever are in England, are due to the same circumstance as the colour which is designedly communicated to the light of different kinds of fireworks. It is a result of the intrinsic natures of the vaporised particles which are made to shine. The vapour of iron has one kind of sheen, and the vapour of sulphur another. Each different foreign ingredient that floats in the air has its own proper hue, which it can communicate to the lightning. The broad flashes of light that appear in the clouds during a thunderstorm, and that are distinguished as sheet-lightning, are very often merely the reflections from the cloud-mist of the discharges that pass from one part to another with each redistribution of the internal charge, as the tension at the outer surface is changed by an external flash. This redistribution of the internal charge is sometimes also marked by very beautiful lines of coruscation playing upon the dark background as the storm drifts away. There is a table-mountain a few miles away from Pietermaritzburg, in Natal, over which this kind of display is continually exhibited. The retreating storm-clouds linger over the flat top of this mountain, where they can be seen from the city, in the advancing night. In this dark canopy of the mountain bright coruscations, accompanying each redistribution of the electrical charge, can be watched for hours at a time—now assuming the form of coronals of electric fire, now running along in machicolated horizontal lines just above the flat top of the mountain, and now radiating out in all directions from a central loop like the cracks of starred glass.

The flash of a discharge of lightning is followed after a brief interval of time by the well-known sound which is recognised as thunder, and of which some account has already been given.* The flash and the sound originate simultaneously, but the flash travels to the eye in an instant, whilst the sound is transmitted through the air to the ear so sluggishly that it does not get quite through 1,200 feet in each second, and so consumes five seconds about every mile of its passage. The sound undoubtedly originates in the shock which is caused in the air by the electric outburst from the cloud. The air is thrown into rapid vibrations which are transmitted on through its substance until they strike upon the ear. As, however, these vibrations are originated in all parts of the lightning's track, and that track is a comparatively extended one, the sound cannot arrive at the ear from all parts of the long path at once, and therefore is necessarily prolonged. This is why thunder is heard as a lengthened-out sound, instead of as a sudden and brief one. What is expressively termed the *rolling* of the thunder—the successive rise and fall in intensity of the lengthened-out sound—is due in part to the varying strength of the vibratory disturbance at different parts of the track, in part to the mingling in of secondary sounds derived from subordinate discharges within the cloud, in part to the interferences with each other of different systems of vibrations issuing from the several points in the track, and crossing each other as they advance towards the listener's ear, and in some instances to resonant echoes returned from reflecting bodies distributed around. All these distinct influences are concerned in producing the alternate subsidence and reinforcement which give its rolling character to thunder.

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* "Science for All," Vol. I., p. 263.

The interval which intervenes between the perception of a flash of lightning and the hearing of the commencement of the roll of the thunder is, as a natural consequence of the circumstances just explained, an exact indication of the distance of the nearest part of the lightning's track. If one second intervene between the flash and the beginning of the sound, the nearest part of the shining track is just 1,180 feet away; if five seconds intervene it is 5,900 feet, or a little more than one mile away.* As a rough estimate, every five seconds of interval may be taken to represent a mile of distance. When fifteen seconds occur between the flash and the beginning of the thunder, the nearest point of the lightning's track may be considered to be three miles away. When the interval of silence is thirty seconds, the discharge is six miles away. The longest interval that is on record as having been marked between a flash of lightning and the consecutive thunder is 72 seconds, which would represent 84,960 feet, or 480 feet more than 16 miles.

But the continuance of the sound for the same reason gives a measure of the distance of the several parts of the electrical discharge, and therefore, with a certain amount of allowance, of the length of the lightning itself. Thus, suppose that in the following sketch (Fig. 1) A represents the position of an observer when a discharge of lightning takes place from a cloud at B, and strikes the earth at C, and that the thunder begins to be heard five seconds after the lightning has been seen; then the point B in the cloud from which the discharge issues is one mile away from the observer's situation at A. But if the roll of the thunder continues for fifteen seconds after it has commenced, this shows that the point C, where the lightning ends, is just three times as far away from the observer as the point B, where it commenced. The sound which originates at D in the lightning's track has twice as long a journey to make before it reaches the ear at A, as that which originates at B. It therefore arrives at the ear five seconds later than the sound which originates at B. The sound which originates at E, in the same way, has a journey three times as long to perform, and therefore arrives ten seconds later; and the sound which originates at C has four times as long a journey, and arrives fifteen seconds later. The whole length of the track B C is consequently three times the measure of the distance of B from A, or, in other words, three miles. Forty-five seconds appear to be pretty nearly the duration of the longest roll of thunder that has been accurately noted. M. Delisle has left a record of a roll of that length which he heard in 1712. This would have given 48,649 feet, or a little more than nine miles, for the length of the lightning, if the discharge had taken place in a course proceeding directly away from the observer. This length of nine miles, it will be observed, very nearly corresponds with the actual length of the flash which was measured by a trigonometrical process at Toulouse by M. Petit.

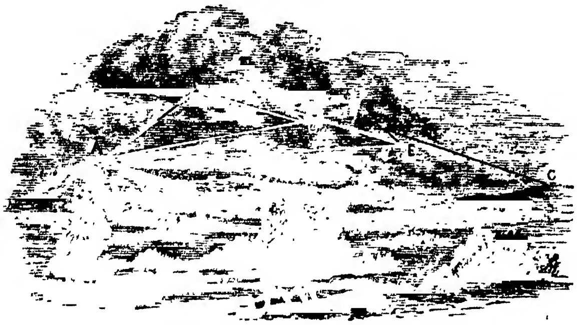

Fig. 1.—Showing how the Length of a Discharge of Lightning can be estimated by the Continuance of the Roll of Consecutive Thunder.

But as a matter of actual fact, a considerable allowance requires to be made in estimating the length of a lightning flash from the duration of the consecutive thunder, because it can rarely happen that the discharge follows a course which proceeds directly away from the observer. It is quite possible, indeed, that a very long discharge may be heard, as a very short roll, if the path which it pursues lies pretty much at the same distance from the observer. Thus, suppose that in the following sketch (Fig. 2) B C represents the track of a flash of lightning issuing from a cloud at B, and striking the earth at C, whilst an observer, stationed at A, is listening for the accompanying thunder. Then the several points, B, D, C, in the track are all, it will be observed, nearly at the same distance from A, so that the sound originating in each would fall simultaneously upon the listener's ear at A. If B, D, and C were all one mile from A, and the length of the flash from B to C were two miles, then the sound originating at B would take five seconds to reach the ear at A; but so also would the sound which originates at D, and that which originates at C. There would, consequently, in such be no prolonged roll of thunder. The three sounds—from B, from D, and from C—would strike upon the ear together, and would be heard as if they were one and the same; and the impression upon the ear would be that of great loudness, on account of the several distinct sounds being combined into one. The terrific short crash which is occasionally heard in thunderstorms is due to this circumstance of the sounds coming from a long track arriving almost simultaneously at the ear.

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* It will be remembered that there are 5,280 feet in a mile.

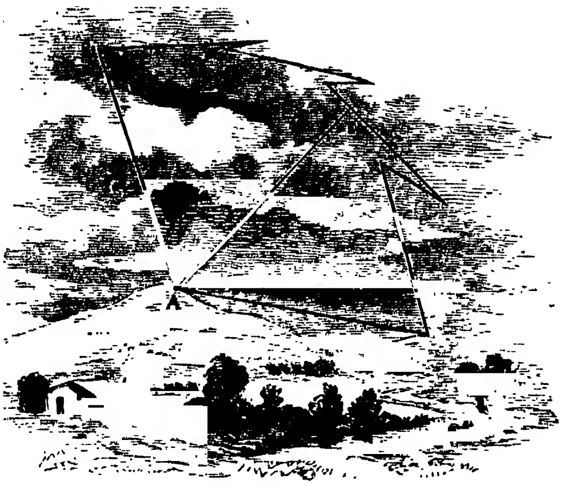

Fig. 2.—Representing the case in which a long Discharge of Lightning keeps approximately at the same Distance from an Observer throughout its Course.

During the progress of a thunderstorm a change continually takes place in the electrical tension, which is maintained for a considerable distance around with each flash of lightning. If a sensitive gold-leaf electrometer be attentively watched during the continuance of the storm, it will be found that the divergent strips collapse more or less with each flash of lightning. Changes in the distribution of the electrical force within the cloud are also commonly indicated in a similar way by movements of the divergent strips of an electrometer, even when no external flash of lightning appears.

Sympathetic disturbances of this inductive character are, indeed, sometimes registered in a very disagreeable and much more obtrusive way, for they are quite capable of producing painful shocks in the bodies of living people, and of perpetrating destructive mischief of a mechanical kind. The curious effect which is known amongst electricians as the return shock, and which at one time was deemed a very puzzling phenomenon, is of this nature. Its occurrence was first alluded to, and intelligently explained, by Lord Mahon in a book* which was published just one century ago. In this treatise he gives an account of an experiment which is still repeated by scientific men, with never-failing interest, as the best illustrative explanation which can be furnished of shocks of this kind.

Two brass cylinders of unequal size, and insulated by being supported upon pillars of glass, were placed about the tenth of an inch apart, as represented at A and B in Fig. 3. The prime conductor of an electrical machine (represented at C) was brought within twenty inches of the outer end of A, and charged with electricity by turning the handle of the apparatus. As this was done faint sparks were immediately observed to pass from A to B, in consequence of the positive electricity of A being driven out from A into B by the repulsion inductively exerted from the prime conductor C. But when B had been thus charged from A, a spark was taken by the experimenter's finger from the prime conductor, and forthwith faint sparks *returned* from B into A. The positive electricity which had been driven into B returned into A when the inductive repulsion of C ceased to act upon A, so constituting the effect which Lord Mahon distinguished as the "return shock." Lord Mahon has furnished a quaint picture in his book, in which he and a companion standing upon glass-footed stools are represented as taking the place of the brass cylinders A and B, and as allowing the faint sparks set up by the induction to pass between the tips of their fingers, held a little distance apart. It is this return shock which is occasionally felt at a considerable distance from the actual track of a discharge of lightning during a thunderstorm. Thus, if L in Fig. 4 represents the place where lightning strikes from a thundercloud to the earth, when C, the opposite end of the cloud, floats a short distance only above the ground, a person standing upon the ground at *a*

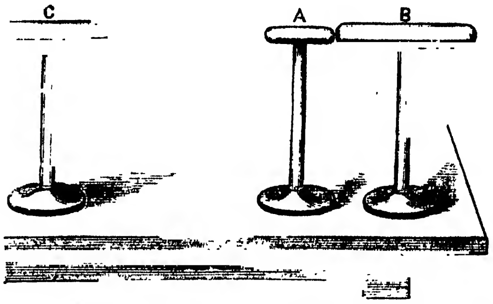

Fig. 3.—Lord Mahon's Experiment devised to explain the Nature of the Return Shock.

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* "The Principle of Electricity" (1780).

might experience an electrical shock at the instant of the discharge of the lightning in consequence of the return from the earth to the cloud of the electricity, which had been just before inductively driven out of that end of the cloud into the earth. There are cases on record of people having been killed in this way at a long distance from the place where the actual stroke of the lightning takes effect. The frequent instances of persons being knocked down by electrical shocks, without being severely injured, or killed, during the progress of a thunder-storm some little distance away, may generally be attributed to subordinate and sympathetic discharges of this character.

It has been said that lightning which presents itself in broad sheets of illumination, instead of as narrow and sharply defined lines of fire, is sometimes merely reflected light thrown back from the clouds or from surrounding objects. It is the glare of lightning, rather than lightning itself, and often produces a very striking and beautiful effect, in consequence of lighting up the edges of the clouds, and showing the broken shapes of their darker masses in strong relief. The clouds seem to *open out* for one brief moment with the flash. There is, however, another and quite a distinct form which sheet-lightning very often assumes. In this the whole sky is for an instant lit up by the glare. When this occurs the source of the light—the actual discharge—is almost certainly below the horizon of the place from which the reflected glare is seen, and hidden from the eye by the intervening curvature of the opaque body of the earth. In such cases the light flashes up from the electrical discharge into the sky, and is thence shot back towards the eye by the impenetrable vapours that it encounters in the canopy of clouds. This form of flash is not uncommonly spoken of as heat-lightning, or summer-lightning. The discharge in such instances is too far away for thunder to be heard. In reference to this kind of lightning, however, it is necessary to remark that M. Peltier, and some other good observers, believe that lightning occasionally issues in the air from clouds which are invisible, or in other words from collections of vapour which are not dense enough at the time to assume the form of aqueous vesicles. Thunder, also, is certainly sometimes heard when no lightning is seen; but that is simply because the light of the discharge is hidden from the eye by quite impenetrable masses of dark cloud.

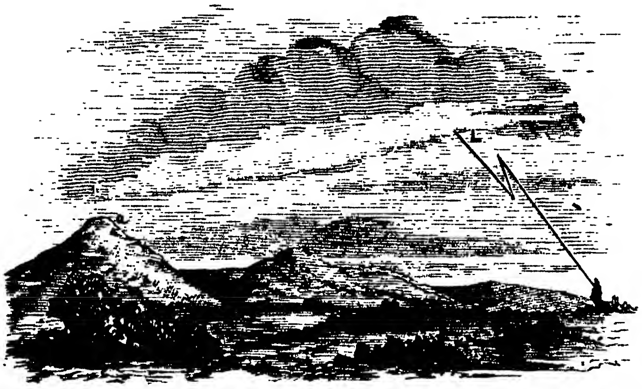

Fig. 4.—Representing how a Return Shock may pass into a Cloud when Lightning is discharged from it into the Earth.

Besides the forked-lightning, which is the incandescent track of the electrical discharge through the air—the electric spark of nature's own experimental operations in the clouds—and the sheet-lightning, which is the reflected glare of that magnificent discharge, there is yet another form of lightning occasionally seen, that is of great interest to scientific men. This is the form which is familiarly spoken of as globe-lightning, or ball-lightning, because it looks to the eye like a ball of fire. Its most distinctive characteristic, however, is the peculiarity of its pace, rather than the aspect which it assumes. It moves at so deliberate a rate that it can be readily followed along its track by the eye as it goes. It has in some well-marked instances been seen in this way for ten seconds at a time. The ball is usually described as appearing to be about the size of the full moon, and it has been observed to rebound from the ground as it advances along its course. It generally disappears at last with a loud explosion, like the detonation which attends upon the firing of a gun. Some observers, M. de la Rive amongst them, have no doubt that this explosion is exactly what it seems, and that it is the result of a mass of hydrogen gas, which has been generated from the electrical decomposition of aqueous vapour and then mingled with a certain amount of air, being fired by the agency of an electrical spark. It is conceived that the explosive mass is, in the first instance, enclosed in a spherical aqueous film, like that of the soap-bubble, and that the light of the ball before its explosion is an electrical radiation, or glow, issuing from this outer shell. It is also held that this glow is only competent for the production of an explosion when it has been intensified and condensed into a spark by some casual incident of surrounding induction. M. Dumoncel attempted, and not altogether without success, to produce a similar result upon a miniature scale by causing a powerful induction spark to pass through small pools of water scattered along a varnished surface. A fiery glow could be then traced, passing along from pool to pool, and terminating at last in the form of a small red ball, which exploded precisely in the manner of ball-lightning. For the present, therefore, ball-lightning may be taken to be an atmospheric manifestation of electrical force of a quite different kind from that with which science has to deal in the instantaneous leap of the "live thunder," and concerning which some further investigation may be said to be urgently required. The German meteorologist Kaemtz, consequently, still remains quite justified for the course which he pursued in his excellent Handbook of Meteorological Science, when he grouped ball-lightning with a series of occurrences and effects which were classed together in its pages as "Problematical Phenomena."

AN EARTHWORM.

By John H. Martin,

Author of "Microscopic Objects," "Manual of Microscopic Mounting," etc.

An earthworm eating earth does not seem a very attractive subject either for investigation or amusement. The information which it yields to patient study and research is nevertheless endless. It is patent to every one that worms live upon earth—not upon leaves, grasses, &c., as was formerly popularly supposed. Doubtless the origin of this mistaken idea was the fact that the earthworm in burrowing into the soil often carries leaves and parts of leaves with it. Still, if closely observed it will be noticed that this is not so much from instinct or intention as from the force of circumstances. If it be remembered that on the surface of the skin numerous thorn-like forms (*setæ*) are seated in pairs at intervals on each ring of the body (Fig. 2, *a*), it will be evident that the worm in passing over the ground (especially if the atmosphere is moist) will entangle small leaves on these hook-like setæ, and as it enters the damp soil the leaf also is carried down, until the friction of the surrounding earth of necessity loosens it from their hold. Although from observation we can prove that the earthworm lives upon earth, it must not be thought that mere earth is sufficient for its subsistence. Most persons will have noticed that in sandy or gravelly soils worms are rarely found in abundance, and in fact never so, except in rich alluvial soils, like meadows near a muddy river and old water-courses, in farm manure-heaps, and in all rich soils containing a large amount of more or less nutrient substances. This fact is soon proved by dissection. Let an earthworm be killed with chloroform (acetic acid or methylated spirit will do); then let it be cut upwards from the under or ventral side, beginning at the anus, which may be known by having a more rounded termination than the head. Next place the worm on a flat piece of cork, pin the sides down so as to expose the contents of the abdomen and intestines; the exact character of its food will then be clearly seen. Generally speaking, this muddy food substance consists entirely of moist earth, but occasionally, if closely observed, portions of organic nutrient matter will be noticed, especially if the substance is placed under the "inch power" of a good microscope. The writer has often tested the assimilative power of the worm by causing it to digest food containing any dye colour, such as carmine or madder. The following are the steps in this process:—Take about half a pint of common white sand; dust in the colour until the sand has acquired the right tint, then pour in a few tea-spoonfuls of salad oil, or use a piece of lard about the size of a walnut. Place the jar on a hot plate, stir the sand until the grease is equally distributed through it, and then let the mixture cool. Now procure a few live worms, place them in the sand, which must have been previously rendered very damp with water, and after a few days it will be noticed that they have been living upon this prepared food, and if its use is continued long enough many of the organs and internal tissues will become partially coloured. This experiment is by no means cruel, as the minute particles of carmine simply deposit themselves in the tissues. It is worthy of remark that worms must cause a large quantity of earth to pass through them before sufficient nourishment has been extracted; in fact, we might judge of the richness of any sample of soil from the number of worms found in it, taking for granted that the soil is damp, as they will not (as we have seen) exist in dry situations. The swallowing of the soil is also of great assistance to the worm as it burrows into the ground; and as large quantities of earth are thereby removed and ejected behind, they are thus great friends to the farmer and gardener, constantly turning up the soil, and often making a barren spot fertile. The old popular belief that worms bite the roots of plants is utterly untenable, as they are not possessed of teeth, having only a very powerful muscular gullet and alimentary canal, by the use of which they obtain and digest their food.

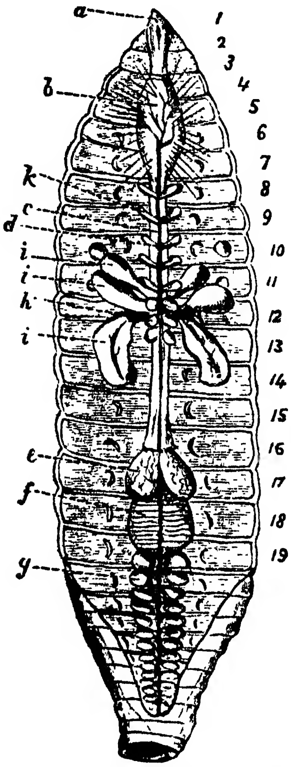

Fig. 1.—Illustrating Anatomy of Earthworm. General View after Dissection.

The manner in which the earthworm swallows earth is curious. Its gullet is extremely muscular (Fig. 1, *b*), and contains an internal muscular tunic, which acts something like the piston of an air-pump when the mouth is applied to the earth, thus sucking it in, and passing it onward by the muscular action of the gullet and alimentary canal. Another point in their structure will strike even a casual observer, namely, that about the twenty-ninth segment or ring of the body there is an enlargement (which generally extends to about seven segments below), having the appearance of an accidental injury to the worm; it is really not an injury, but an important part of its structure. Its tissues are glandular, their chief use being to assist the other tissues at the time of the reproduction of the species. This part of the body, called the "cingulum" or "clitellum," is entirely free from the setæ, and the segments are less prominent in their muscular character, which tends to give the appearance as before mentioned of a diseased or injured worm. In a well-grown worm there are about 350 segments or rings, although the general average is much less, namely, about 150. To observe the various systems of structure, it is necessary to take another worm: in this case the larger the better. Kill with chloroform, place it upon the loaded cork, and insert a pin through the first segment. Then with a sharp scalpel make an incision either along the belly or the back, from the mouth to the thirtieth segment; turn back the sides as far as possible, and fix them with pins; place in a shallow dissecting trough (a small white saucer would do), and cover with alcohol. Next with a fine camel's-hair pencil brush away any undigested earth or other matter from the organs left exposed. Gradually, as the alcohol hardens the tissues (a few drops of bichromate of potash may be added) they become more apparent to view (Fig. 1). On observing the opened worm, the skin, muscular, digestive, and circulatory systems are apparent, but the nervous, reproductive, and other systems are more obscure, and require the aid of a good microscope to work out their structure. The muscles of the gullet will be known by their strongly developed character (Fig. 1, *b*). The tegumentary (*i.e.*, skin tissue) is so closely linked to the muscular system that in describing one we really, or at least partially, describe both. Each acts with and by the other, although the muscular is the more important.

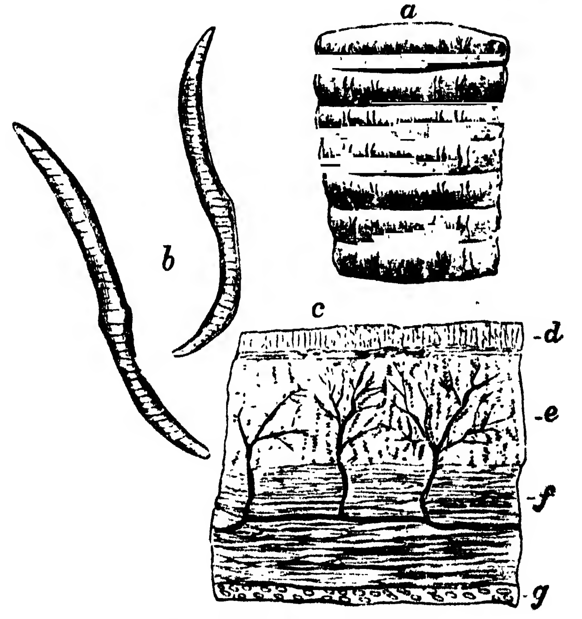

Fig. 2.—Tegumentary System.

a, Setæ in position (slightly magnified); *b*, Pair of Setæ (magnified): *c*, Transverse Section of Skin (greatly magnified); *d*, Epidermis; *e*, Pigmentary Vascular Layer; *f*, Muscular Tissue; *g*, Epithelial Layer of Cells.

On nearly every segment of the body there are four bristle-bearing glands (Fig. 2, *a*); in each gland is inserted a pair of setæ, or bristles. From these glands there appears to be a gradual enlarging or reproducing these bristle-like (setæ), so as to re-supply or rebuild, according to the amount of injury sustained in their daily use. Some of the setæ will be found much larger than others, proving that there are old as well as recent formations. To thoroughly study the skin, a transverse section must be made. To do this well, the student ought first to stain the tissue with hæmatoxylin or picro-carmine, and then imbed it in gelatine or glue in the following manner. Soak the glue or gelatine in water until it is "jelly-like," then dissolve in glycerine and gum-water, equal parts, with the aid of heat. The piece of skin to be cut must be well soaked in water previous to its being imbedded in the mixture; when well imbedded place the mass between two *greased* slips of glass, and allow the glue to dry. Then when it is sufficiently dry, very thin sections may be easily cut with a sharp scalpel, the section having the appearance of that figured (Fig. 2*c*); the upper portion (*d*) showing the structure of the epidermis, the second layer (*e*) consisting of a kind of pigment tissue, and the third (*f*) the muscular tissue, which is generally the thickest, consisting of a multitude of minute fibres crossing in all directions, those nearest the surface of the skin running parallel with the body, and those that are more deeply seated transversely.

The muscular tunic, which runs the entire length of the worm, is at intervals constricted into rings, or "annulated." If a worm is held tightly between the fingers, the movement of these muscular rings will be self-evident, requiring a most severe pressure to prevent the progress or "wriggling" of the animal. The muscular tissue (Fig. 3) of an earthworm is unlike that of the higher animals. It consists only of a simple contractile tissue, connected with stronger muscular fibres at points where the necessary power is required. It might indeed be compared to a thin sheet of india-rubber, not having the striated structure of the voluntary muscles of the back-boned animals. In the first few rings of the body strong radiating muscular fibres diverge from the transverse muscles (Fig 1, *b*), thus immediately connecting the gullet with the "tegumentary" or skin tissue. Part of the muscular coat which terminates this tissue forms the lining of the pharynx, and acts as a kind of disc or sucker. By the force of its own contractile energy this coat draws the food into the cavity, and continues its action under the control of the worm. Another important use of the muscular tissue is to keep the setæ in their natural position, so that these hooks, or thorn-like bodies, may yield to pressure from the substance through which the worm is forcing its way, but at the same time offer great resistance to any other substance meeting them from an opposite direction.

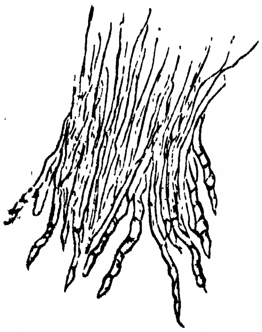

Fig. 3.—Muscular System and Muscular Fibre of Earthworm.

The next prominent feature to which attention must be directed is the digestive system. The mouth of the earthworm is a conical-shaped structure, comprising the first segment of the body; it consists of fleshy or muscular tissue—in fact, it is a kind of lip: the movement seems to be the same as other parts of the muscular tunic. The pharynx, as already mentioned, is an exceedingly muscular organ, situated immediately below the mouth (Fig. 1, *b*), and extending from the second to the seventh segment: the back and sides are its most muscular parts.

As we trace the course of the alimentary canal (Fig. 1) we next come to the œsophagus, commencing at the eighth segment and continuing to the fifteenth or sixteenth. The œsophagus consists of a narrow but highly muscular tube, having an inner mucous lining or membrane. It appears to assist in two functions, viz., the digestive and the circulatory. If the worm, opened in the manner already described, or the woodcut (Fig. 1) is examined, it will be noticed that the dorsal blood-vessel, which runs parallel to the course of the alimentary canal, is here more highly developed (Fig. 1, *k* and Fig. 5, *f*).

It is supposed that the alternate muscular movement of the œsophagus, as the food passes down the alimentary canal, acts upon this dorsal vessel, and tends greatly to assist in the circulation of the blood. At the termination of the œsophagus at the fifteenth or sixteenth segment, the digestive apparatus expands into a kind of stomach; this is heart-shaped, and may be easily distinguished by its strong muscular appearance (Fig. 1, *e*), which is also horny to the touch, especially after treatment with alcohol. This stomach, or "crop," occupies but little space, rarely taking up more than one or two

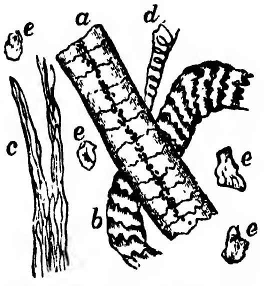

Fig 4.—Hairs, &c, taken from "Crop."

a, Human Hair; *b*, Wool; *c*, Woody Fibre; *d*, a Spiral Vessel; *ee*, Particles of Sand.

segments of the body, and is found, as a rule, between the sixteenth and seventeenth segments. We now come to the so-called "gizzard," which is really a hard tube or ring immediately below the stomach; this occurs between the eighteenth and nineteenth segments. The organ (if it is one) has not been thoroughly investigated. Immediately below this are the intestines (Fig. 1, *g*), which pass through the rest of the body to the anus (or vent) with but little alteration in their structure. Although the length of the intestines is great in nearly all vertebrate animals, they are much exceeded—proportionately—by those of the worm. This illustrates an interesting point in the economy of nature. If the worm had less length of intestine its movements through the earth could not have been so rapid; as it exists, the food is forced up or down according to the obstacles met with, without any of the inconvenience to the animal, which would be the case if the length were less. In the twelfth and thirteenth segments (Fig. 1, *h*) are seated three pairs of glands, which have been found to secrete a milky fluid, which probably aids in assisting digestion: their functions may be considered, at present, rather obscure. It may be added that the muscular coat of the intestines, though delicate in structure, seems to have great power in propelling the food onward.

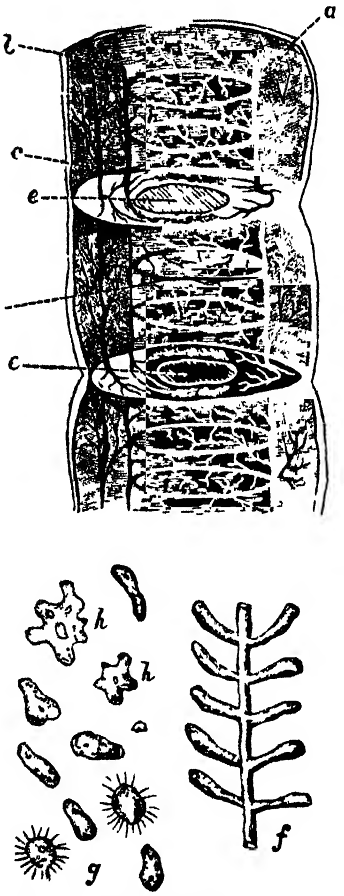

Fig. 5.—Circulatory System: *a*, Dorsal Vessel; *b*, Sub-intestinal Vessel, *c*, Ventral Vessel. *d*, Deep Commissural Vessels, Corpuscles, &c., of Perigastric Fluid· *e*, Alimentary Canal (slightly enlarged), *f*, Laterodorsal Vessels, or Hearts (magnified), *g*, Colourless Corpuscles of the Perivisceral Fluid; *h*, Amœboid Corpuscles (greatly magnified).

In the order Annelidæ, to which the earthworm belongs, the circulatory system has been found to consist of two separate fluids, answering to the arterial and venous blood of higher animals. Both of these might justly be called blood, although in colour one only can be considered as entitled to that claim. The colourless fluid, which has a more or less milky appearance, contains corpuscles and cells in process of development (Fig. 5, *g*). The coloured fluid, which does not contain corpuscles, runs in a system of vessels (Fig. 5, *a*, *b*, *c*, *d*); the colourless (or nutritive) circulates in a large cavity between the alimentary canal and the muscular integument of the skin; it has therefore space wherewith to bathe the various organs of the body with its nourishing corpuscles (Fig. 5, *g*). This space is called the perivisceral cavity.

On examining this fluid, it will be as well to allow a drop to partially evaporate under a thin glass circle laid upon a glass slide three inches by one. Drop one drop of crimson aniline dye close to the edge of the circle, when it will flow in from capillary action; after an interval of ten minutes place the object between a wire clip, and lay the slide in water.

After a short time the waste dye will pass off into the water, leaving the corpuscles, some of which will be found dyed; place one drop of glycerine at the edge of the cover, and as the water evaporates it will supply its place: this takes about twelve hours. Seal the slide with india-rubber cement, giving two or three coatings, washing the surface before placing a fresh layer of cement, otherwise the glycerine will exude from the preparation.

It has been proved that this colourless blood has communication with the exterior part of the body in two ways: first, through a series of pores—one of which occurs in every segment, with the exception of the first seven or eight; the other with the so-called segmental organs. These organs communicate with the external part of the body by means of a long tortuous tube, or canal, terminating at the other end in an open expansion of the tube, through which this white or perigastric fluid flows to the surface of the skin. That these pores have the power of absorbing fluids from the surrounding external matter is easily proved by touching the extremity (anus) of the worm with a few drops of any staining fluid, such as an aniline dye in water. The staining is thus made apparent. As the small absorbent vessels can easily be seen under the microscope, the corpuscles of this fluid, the size of which ranges from $\frac{1}{1000}$ to $\frac{1}{3000}$ of an inch, are most interesting, partaking as they do of many varied forms; and if observed quickly after killing the worm, the amœboid movements of a few of the corpuscles is a sight worth seeing to any student of science.

A remarkable and interesting form of life is found in all parts of the alimentary canal, though its minute bodies must not be confused with the blood corpuscles of the perigastric fluid (Fig. 5, *g*). This is a parasite known as *Gregarina*. Though its life history has not been fully traced, we know that all the species exist as parasites, especially in the intestinal canal. They occur as round colourless sacs, containing minute oval bodies, which bear a remarkable resemblance to a species of diatom, called *Navicula* (Fig. 6, *b*, *c*). Having thus partially explained the action and character of the colourless, or perigastric, fluid, it is necessary to give a slight sketch of the coloured, or as it is called, the vascular or non-corpusculated fluid. It circulates in a series of vessels having three principal trunks (see Fig. 5): first, a dorsal vessel, running from the eighth segment to the length of the back of the animal; another called the sub-intestinal, running from the fourth or fifth segment; and a third, called the sub-neural, or ventral, which lies beneath the ganglionic or nerve cord (Fig. 6, *a*). The vessels on the back and under the intestine are connected by the so-called deep commissural (spinal) or central vessels in each segment of the body, with the exception of the first few front segments. These in connection with the stomach and gizzard (Fig. 1)—*i.e.*, in the sixteenth to nineteenth segments—distribute capillary vessels to the fibrous structure of the stomach and gizzard.

Where these connecting vessels encircle the intestines they are closely attached to the wall of the intestine, and generally imbedded in the yellow granular-like substance covering its surface, which, according to some authorities, has a biliary function. In the earthworm the superficial skin circulation of the blood, such as occurs in higher animals, is wanting. The commissural vessels give off various branches to the intestines, and both the supra-intestinal (dorsal) and the sub-neural vessels give off large branches to the muscular and other tissues of each segment. In the first seven segments of the body the larger vessels are wanting, their place being taken by a network of minor vessels. Behind the reproductive organs, if carefully thrown back, the commissural vessels will be found to be greatly dilated, forming about six to ten pairs of the so-called hearts (Figs. 1, *k*; 5, *f*). Formerly the large muscular sac or stomach, which will be noticed by any observer, was thought to be the heart.

The nervous system of the worm consists of a two-lobed ganglion, or two ganglia closely united (Fig. 6). In either case these are situated in the third segment of the body; from them spring a supra-intestinal and sub-intestinal chain of ganglia, with their branches (Fig. 6, *a*). In the case of the sub-intestinal chain of ganglia the cord is double, but at the posterior end of the body they become closely attached, the ganglionic enlargements varying in shape and size at various parts of the body. Each gives off from the sides two pairs of nerves, which again sub-divide into filaments spreading through the muscular and other tissues. From the united ganglia, which are seated in the third segment, nerve-fibres are distributed to the lower part of the first segment, which thus tends to give the mouth its extreme degree of sensitiveness; in fact, so remarkable is this part of the body, that some of our best authorities on the subject suggest that possibly other senses than that of touch exist in it, though in a rudimentary form.

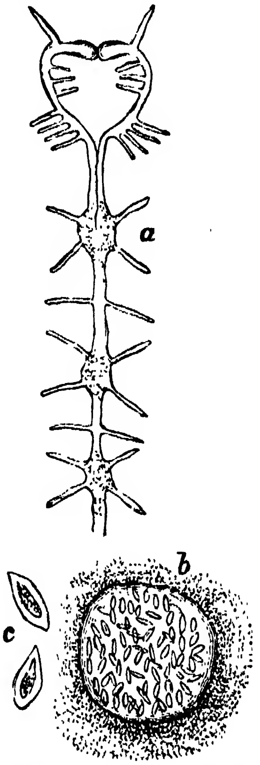

Fig. 6.—*a*, Nervous System of Earthworm; *b*, Gregarina; *c*, Navicula-like Bodies, free (magnified).

Other minute glands, &c., occur in the anatomy of the earthworm, but in this brief outline any notice of their structure, and of those organs essential to the perpetuation of the species (Fig. 1, *i*), is scarcely necessary.

These can be seen by killing a worm or worms, as occasion requires, with chloroform. It ought, however, to be remembered that a fresh dissection is always best; after the lapse of one day, even if kept in alcohol, the various structures lose their character to a certain extent, making it more difficult for the student to recognise each separate organ and tissue.

In the investigation of these various structures it is necessary to make use of artificial means wherewith to more easily ascertain the exact character of the tissue under examination. To do this we make use of dyes or staining fluids, taking advantage of the fact that there are two definite kinds of "matter," *i.e.*, "germinal matter" and "formed matter." The "germinal" or forming matter will soon take the stain, but the "formed" matter resists being coloured; and, according to its various stages of transition into "formed matter," the cells will be dyed different tints, the most recent deeply, and the older but slightly.

Various dyes act differently upon animal matter. One of the best—at least, to begin with—is the carmine staining fluid.*

By agitation and the aid of heat the carmine will dissolve in the ammonia. Boil this solution for a few minutes in a beaker and allow it to cool. After one hour add the alcohol, glycerine, and water, then stir, allow it to settle; finally, pour off the clear fluid, and bottle for use. If this is found to be too much trouble, use an aniline dye in water. There are many other staining fluids, but these will be sufficient for our purpose. Nearly all animal tissues take the dye more or less if previously plunged into a weak solution of either soda, potash, or ammonia, allowing them to remain for about thirty minutes. Transfer the tissue to the dye, let it remain from five to fifteen minutes; well wash in water to which a few drops of acetic acid have been added, drain the washing fluid off, and transfer a few minutes to spirits of wine, and subsequently to glycerine. After one hour mount the preparation in glycerine jelly; this will be found much better than pure glycerine, as it is not so difficult to seal with the india-rubber cement. If well mounted, the preparations will last for years.

The only instruments necessary for the examination of a worm are a pair of long-bladed scissors, a fine scalpel, two needles, mounted in cedar handles—one bent at right angles, the other straight—pins, and a piece of cork loaded with sheet lead, which should cover the bottom, and turn up over the edge of the upper surface. It is well to make the dissections with a lens of long focus. One of the small hand-glasses used for examining photographs or a watchmaker's "eye-glass" will do.

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* Martin: "Manual of Microscopic Mounting," p. 198. Carmine, ten grains; liquor ammoniæ fort., half drachm; glycerine, two ounces; distilled water, two ounces; alcohol, half ounce.

WHAT IS AN ELEMENT?

By G. W. von Tunzelmann, B.Sc.

In ancient times there was no very definite meaning attached to the word element. Some thinkers—among whom was the Greek philosopher Sanchoniatho—affirmed that air and water were the primary elements of which all other kinds of matter were built up. By others fire was called an element, and was believed to enter in some manner into the constitution of many substances, some of them asserting that earth of various kinds was composed of different combinations of fire and water.

There were others again who considered earth to be an element, and even down to our own times these four—fire, air, earth, and water—have been popularly known as the "four elements," without, however, any definite idea being attached to the word.

In the early times in which such speculations were rife, men who wished to form theories about the universe did not trouble themselves with actual investigations into natural phenomena. They considered their own minds to be infinitely superior to nature, and accordingly, when they wished to propound a theory of the world, they first evolved it out of their own inner consciousness, and if they afterwards deigned to compare their results with the actual phenomena of Nature, it was only to endeavour to make Nature fit in with the conclusions at which they had already arrived. We can trace the results of this method of reasoning in all the speculations of the early alchemists.

The alchemists noticed that most of the metals with which they were acquainted were easily altered by heat or by the action of other substances, and these they called imperfect metals; gold and silver, which remained unchanged after exposure to fire, and resisted the action of nearly all the substances which acted upon the others, they called perfect metals. The alchemist Salmon tells us that it was not the intention of Nature to make such metals as iron, copper, tin, or even silver, although this metal is of the first degree of perfection, but that its object was to produce gold, since Nature in its wisdom seeks in all its works the highest attainable perfection. Hence he tells us that we must consider the imperfect metals as abortions, due to the action of external causes which have prevented Nature from following its own course.

Again, it was observed that most of the metals were found in different states in the earth, and these were supposed to represent different degrees of perfection. The fact that the same metal could be obtained from these different ores, as we should now call them, was considered to prove the possibility of transmuting the so-called imperfect metals into silver or gold.

Until the twelfth century, most of the Greek and Arabian philosophers who occupied themselves with these questions were content with reasoning about the possibility of such transmutations, without seeking for any special substance by means of which they could remove the impurities of the imperfect metals, and so transmute them into silver or gold. About this time, however, the philosophers began to search for such a substance, which they called the philosopher's stone.

Here, again, we always come across their great central idea of something that was to remove all imperfections, for, according to the alchemists the philosopher's stone, when found, would not only transmute any metal into silver or gold, but it would heal all diseases, and indefinitely prolong human life.

The alchemists Salmon and Nicholas Flamel both tell us that the possession of this wonderful substance will change the most wicked man into one who is kind and charitable, and whose chief pleasure is in the contemplation of the wonderful works of the Deity. Many later alchemists try to draw analogies between the mysteries of alchemy and those of Christianity, and almost all of them considered themselves to be under the special protection and guidance of the Almighty, though popular prejudice usually associated the alchemists with the powers of evil.

Although alchemy was mixed up with much superstition, and was seeking an unattainable object, yet we must never forget that the alchemists were the first to institute experimental research, and in the course of the immense number of experiments made by them in the fruitless search after the philosopher's stone, they investigated the properties of various metals, and discovered a large number of chemical compounds; and thus they prepared the way for the modern science of chemistry.

The science of chemistry is considered to date from Lavoisier's discovery of the nature of combustion. He showed that when a substance is burnt in air, it enters into combination with a constituent of the air, which we now call oxygen, and in this way he demonstrated the compound nature of air.

It is to the researches of Lavoisier upon the metals and their oxides, or compounds with oxygen, that we owe the idea of an element as a substance which cannot be decomposed by any means at our command into simpler constituents. This is what we now understand by an element, and Lavoisier, by demonstrating the elementary character of the metals, put an end to the hopes of the alchemists, which could only endure so long as the metals were regarded as compound bodies.

Since the foundation of the science by Lavoisier, chemistry has advanced with rapid strides, and we are now able to state, as the result of numberless chemical investigations, that all kinds of matter known to us on the surface of the earth are composed of a comparatively small number of elements, or substances which hitherto we have been unable to decompose.

As the means of chemical research become more extensive, some of the bodies which had before been regarded as elementary are found to be compounds; thus potash and soda were regarded as elements until 1807, when Sir Humphry Davy showed that they were oxides of two metals, which he named potassium and sodium.

On the other hand, new elements are discovered from time to time, and several metals, occurring only in very small quantities, have been discovered by aid of the spectroscope. The following is a list of the substances at present included under the term "Chemical Elements":—*Non-metals or metalloids*—arsenic, boron, bromine, carbon, chlorine, fluorine, iodine, nitrogen, oxygen, phosphorus, selenium, silicon, sulphur, tellurium; *metals*—aluminium, antimony, barium, beryllium, bismuth, cadmium, caesium, calcium, cerium, chromium, cobalt, copper, didymium, erbium, gallium, glucinum, gold, hydrogen,* indium, iridium, iron, lanthanium, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, niobium, osmium, palladium, platinum, potassium, rhodium, rubidium, ruthenium, silver, sodium, strontium, tantalum, thallium, thorinum, tin, titanium, tungsten, uranium, vanadium, yttrium. zinc, zirconium. In addition to these the discovery of several new metals has been announced in the course of the last two or three years, but these discoveries have not yet been sufficiently confirmed to justify their insertion in the foregoing list.

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* Until lately hydrogen was classed among the metalloids, but it is now considered to be a true metal.

The most recent discovery of the compound nature of bodies hitherto regarded as elementary, and one of the very greatest importance in its theoretical bearings, is due to Professor Meyer, of Zurich.

During 1879, and for some years preceding, Professor Meyer had been making experiments with a view to determine the densities of various substances when in a state of vapour, and he succeeded in introducing numerous improvements in the methods employed, more especially, in relation to our present subject, he devised a method of determining with very considerable accuracy the vapour densities of substances at high temperatures.

Professor Meyer proceeded to investigate by this new method the vapour densities of a large number of compounds and elements, but did not obtain any results that bear on the question we are now considering until he came to chlorine, a gaseous body which has hitherto been regarded as an element. The chlorine was obtained by introducing into a heated tube forming part of the apparatus for determining the density, a small portion of platinous chloride, a compound of chlorine and platinum, which splits up into its two components when moderately heated.

It was found that when the temperature was about 800° C., or higher, the density was lower than could be accounted for on the ordinary hypothesis regarding chlorine.

Similar results have been obtained by Professor Meyer with iodine and bromine, two substances closely related to chlorine in their chemical properties, and which, together with chlorine, have up to the present time been regarded as elements.

These experiments led Professor Meyer to the conclusion that chlorine, bromine, and iodine were really compounds, and this conclusion is now generally accepted. Professor Meyer believes that oxygen is one of the components of chlorine, but this has not yet been confirmed.

If, instead of forming the chlorine at the temperature of experiment by the decomposition of platinous chloride, free chlorine previously prepared be employed, it is found that the dissociation does not take place, giving the curious result that previously prepared free chlorine remains unchanged at high temperatures, while nascent chlorine—*i.e.*, chlorine at the moment of its liberation from a compound (viz., platinous chloride)—is dissociated.

Having, then, clearly before us what we understand by an element, the important and interesting question presents itself to us—viz.: Are the elements merely compounds in varying proportions of a few simple substances, or of one primary form of matter? or, on the other hand, are the greater number of them really fundamentally different forms of matter?

A priori, we should be disposed to believe that all the elements must be modifications of some one primary form of matter, for it falls in well with that faith in the simplicity and the unity of nature, which has led to so many grand scientific discoveries, and it is an hypothesis which also falls in so conveniently with the nebular theory of the origin of the universe. But let us remember the errors of the alchemists and early philosophers who reasoned from their ideas of the fitness of things, instead of questioning nature with unprejudiced minds. Faith in the unity of nature is of the greatest value in directing and stimulating our inquiries, but it must never be allowed to take the place of experimental research, which is simply the direct questioning of nature.

In order to put this question to nature regarding the elements, we have to seek the aid of the spectroscope, in order to inquire whether those elements which we have not been able to decompose by the highest temperatures attainable in our laboratories may not be broken up by the far higher temperatures of the celestial laboratories.

It is, then, to the sun and the other self-luminous stars that we must look for an answer to this question.

In 1873 Mr. Joseph N. Lockyer pointed out that the results of some of his spectroscopic researches upon the sun and other stars appeared to indicate that the elements—or, at any rate, some of them—are really compound bodies.

These results show that the hotter a star is, the simpler is its spectrum; in other words, the fewer are the elements which it contains, and in some very brilliant stars he was able to detect the presence only of hydrogen and the metal magnesium.

In colder stars, such as our sun, are found a considerable number of metals, but no metalloids or compounds, and in still colder stars metalloids and metallic compounds are found, but no metals in the free state.

Mr. Lockyer believed that the probable explanation of these results was that the metalloids and some of the metals were decomposed at such high temperatures as that of the sun and some of the hotter stars, and that the spectrum became simpler the hotter the star, because the higher the temperature the fewer were the elements which could remain undecomposed. Professor Meyer's discovery of the possibility of dissociating chlorine, bromine, and iodine offered a strong confirmation to this view, as far as the metalloids were concerned.

Since first communicating (in December, 1878) the result of his four years' work upon the solar spectrum, Mr. Lockyer has continued his researches, and more especially he has compared with great the spectra of different parts of the sun which are at different temperatures. This comparison shows that the spectra of the hotter parts are much simpler than those of the cooler, and these results, as well as his other researches in this direction, tend to strengthen the conclusion that the so-called chemical elements can be broken up where a sufficiently high temperature is attained, and that many, at least, of the substances at present thought to be elements will be found, as our knowledge of their constitution advances, to be compound bodies.

PHOSPHORESCENCE.

By William Ackroyd, F.I.C., etc.

In the ineffectual attempt to strike a match in the dark, probably everybody has seen the faintly luminous track that has been left wherever the match has been rubbed; it may likewise have fallen within the experience of many of our readers to see fish that have caused the housewife no small amount of surprise by their shining appearance in the dark pantry, and perhaps both phenomena will remind the seafaring man of a similar light he has seen in the wake of his ship as she has sped through the waters in the darkness of night. The appearance in each case is a pleasing and a striking one, and our interest in it has been increased by the song of the poet and the comment of the philosopher. To the latter, indeed, it has been somewhat of a puzzle, as presenting a kind of light differing from that furnished by sun, moon, and stars, or the artificial light-sources that have been devised in these latter days, and he has accordingly attempted to ascertain something more about it than could be learnt by casual observation. A sketch of what he has made out will probably be of interest to the reader.

A moment's consideration of the first experiment will teach us the meaning of the word *phosphorescence*. A match, as we already know,* is tipped with phosphorus, an element whose name signifies that it bears or emits light. It is a small trace of this substance, left where the match has been rubbed, that glows in the dark. Hence any body which shines faintly when taken into a dark room is said to behave like phosphorus, in one word, to *phosphoresce*, and all such phenomena come under the one general heading of *phosphorescence*. The housewife saw the phosphorescence of a fish, and the sailor witnessed the phosphorescence of the sea.

Fig. 1.—Noctiluca miliaris.

Phosphorescence is to be observed in all the three kingdoms of nature, being exhibited by animals (living and dying), by vegetables, and by minerals. And first as to animal phosphorescence. In 1810, it was shown by M. Suriray that the phosphorescence of the sea in the English Channel is owing to the presence of an organism called *Noctiluca miliaris* (Fig. 1), a minute rhizopod which requires a high magnifying power to get a good view of it. This is an example of a living phosphorescent animal. It is not, however, the only one which is found in the sea, for Sir Joseph Banks found a phosphoric crab in the waters of the South Atlantic, and many soft-bodied animals (molluscs) have been met with which are self-luminous. Of other living organisms which exhibit phosphorescence it has been pointed out by Dr. Phipson, that, "With the exception of a few more or less doubtful cases, the faculty of producing light seems in the animal world to cease with the class of insects. But, on the other hand, from insects downwards there is scarcely a section of the animal world but which furnishes us with some self-luminous beings." In answer to the question, What is the cause of the light emitted by these animals? nothing has yet been offered but suppositions. In the case of *Noctiluca*, Ehrenberg thought it might have a number of light-emitting organs, for upon submitting the animal to a magnifying power of a hundred and forty diameters he found the uniform luminosity to disappear and become concentrated in a number of brilliant points, just as the astronomer finds that the faint luminous area stretching across the heavens, and known as the *milky way*, is resolved by very powerful telescopes into a number of brilliant points known as nebulæ. What may be taking place in one of the phosphorescent points of a *Noctiluca* is one of the many hidden mysteries that science has yet to reveal.

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* "Striking a Light," "Science for All," Vol. I., p. 142.

Among living insects there are some that are remarkable for their power of emitting light, as, *e.g.*, the glow-worms and the lantern-flies. The glow-worm (Fig. 2) belongs to the genus *Lampyris*, of which there are many species that are luminous. Schultze has made an examination of *Lampyris splendidula*, and finds the male to possess two light-producing organs. They are thin whitish plates which lie on the under side, nearly at the end of the body. These plates are composed of two layers, a front one, yellowish, transparent, and very luminous; and a back one, white and opaque, from the presence of a great multitude of doubly reflecting granules, which Kölliker supposes to consist of urate of ammonia. Branches of the insect's breathing tubes (tracheæ) ramify among the cells of the front layer, and end in star-like corpuscles.

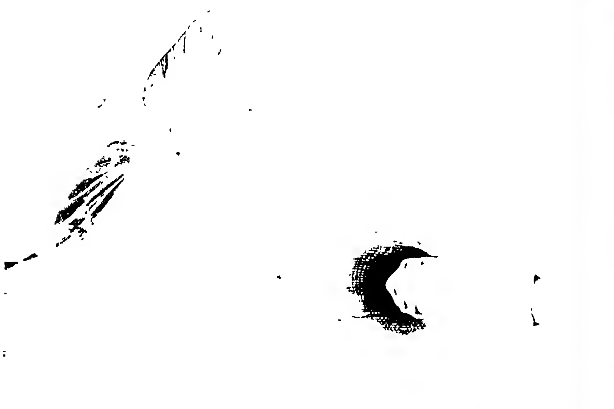

Fig. 2.—Male and Female Glow-worms. Male winged, female wingless.

As to the cause of the light there have been many different opinions. Matteuci made a series of experiments upon *Lampyris Italica* with the idea of proving the light to be due to combustion. Since, however, combustion is attended with the development of heat, and this experimenter detected no sensible heat to be produced in his experiments, it has been held that Matteuci's hypothesis is untenable. A stronger objection, however, was furnished by the fact that when Matteuci placed the phosphorescent substance of the insect in hydrogen or carbonic acid, gases which do not support combustion, the light still continued to be emitted for thirty or forty minutes. It must, however, be said in fairness, that even in this experiment an advocate in favour of the hypothesis might maintain that the continuance of light is due to some extent, if not wholly, to the residual oxygen still remaining in the air-tubes of the insect after removal from the air to the hydrogen or carbonic acid. But whatever it may be due to, it doubtless subserves many useful purposes. The light of the little organic lamp illuminates the insect's path, and probably discloses to its minute and sensitive eyes that of which it is in quest, although at times it may be a source of danger, as when it serves as a mark for some voracious bird, which, like Cowper's nightingale, is in want of a supper.

Numerous species of insects belonging to the genus *Elater* are phosphorescent, and they are generally known as fire-flies (Fig. 3), and are referred to by Southey in "Madoc," and by Longfellow, who in the "Song of Hiawatha" gives us the red man's idea of their character.

As we have said, the different kinds of fire-flies are very numerous. Kirby and Spence state that from Chili to the south of the United States, there are seventy distinct species. The *Elater noctilucus* of Latreille has perhaps been most studied. It is of a dark brown colour, attains to a length of about one inch and a half, and has two yellow spots on its back, which shine very brightly at night. Hidden under the wing-cases there exist two other luminous spots, so that when the insect is flying it shows four lights of great brilliancy as such lights go. The light it emits is more vivid than that given out by the glow-worms, and it is said that the light emitted by the two spots on its back is sufficient alone to read small print by.

Phosphorescence is often an accompaniment of the cessation of animal and vegetable life. The bodies of most marine animals shine after death, and phosphorescence has been observed in the dead flesh of man, lamb, and calf. Dead fish, more especially the herring and mackerel, are noted for their shining appearance when they have been exposed to the air for some time; but beyond having noticed what favours and what disfavours the phenomenon, we are very little better off in our knowledge of the subject than the ancients were. It appears to have been made out that the phenomenon is not due to the presence of animalculæ, and from other observations it is believed that the phosphorescence is the result of some state which precedes putrefaction. From this it would seem to follow that the phosphorescence in these cases may be a physical one, allied to that presented by minerals such as we will presently describe.

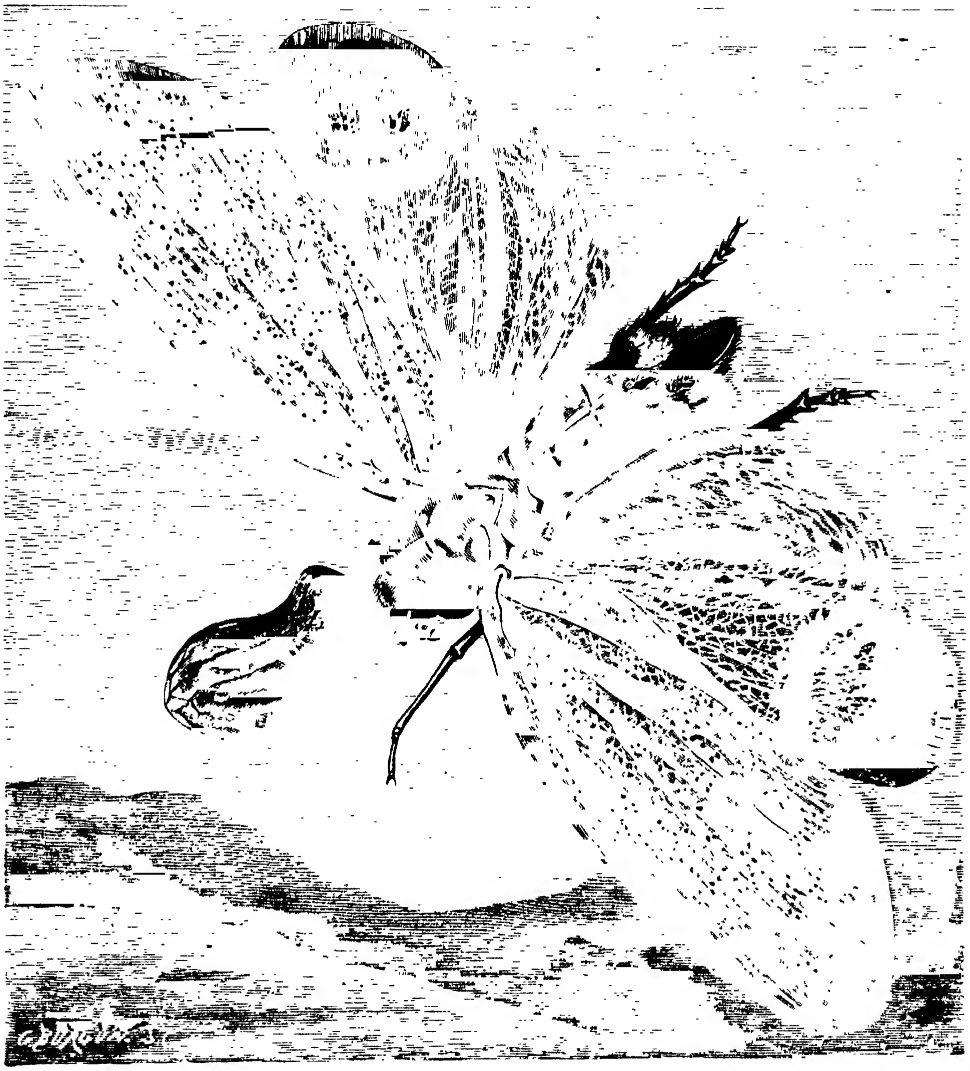

Fig. 3.- The Great Lantern, or Fire-fly.

The luminous appearance of decayed wood in the dark, which will probably be a sight the reader is quite familiar with, has been known from the earliest times, and is mentioned by Pliny, who refers to the light emitted by "the trunk of the oak when it has become rotten with old age." The luminosity displayed here has been attributed to cobweb-like fungus; and respecting its physica cause it has been found that moisture increases it, and that an atmosphere of pure nitrogen is as favourable to its manifestation as one of pur oxygen. Decaying potatoes likewise emit a fain light in the dark.

But perhaps the most remarkable example of undoubted vegetable phosphorescence is that furnishe by a red mushroom, the *Agaricus olearius* (Fig. 4 During the night it emits a bluish light which i complementary to its colour; in other words it is a organic instance unique in its way, of the reciprocit of radiation and absorption,* for during the day th fungus absorbs certain rays of the sun, and gives out during the night somewhat similar though much less intense rays. The behaviour of the fungus has been studied by MM. Delille and Fabre, and from their separate observations it would appear that the young mushroom is phosphorescent for many successive nights, even when uprooted from the olive-tree at the foot of which it grows; that dampness or dryness of the air does not appear to influence its light, and that no elevation of temperature can be observed in the parts which shine. It would seem, therefore not improbable that we have here a case of phosphorescence similar to that of sulphide of calcium, and many other substances which require first to be exposed to the rays of the sun before they will shine on their own account in the dark.*

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* "Getting Warm," "Science for All," Vol. III., p. 268.

The cases of mineral phosphorescence are of surpassing interest, because of the readiness with which in most instances the phenomena may be produced, the softness and beauty of the light emitted, and the possibility there now seems of some of these phosphorescent substances being utilised for making luminous paints. In November, 1877, a patent was applied for by Professor Balmain, under the title "Improvements in painting, varnishing, and whitewashing," and the patent covers the mixing of phosphorescent substances with any vehicle that will form what is commonly called a paint, wash or varnish. Small cards coated with Balmain's luminous paint are offered for sale, labelled "a trap to catch a sunbeam," and with such a trap the reader may try some very interesting experiments. It will be found that if the card be exposed to the direct rays of the sun, it shines with a somewhat violet light when it is removed at once into a dark room. This placing of a phosphorescent substance in sunshine is termed *insolation*, from the Latin, *in*, into; and *sol*, the sun.

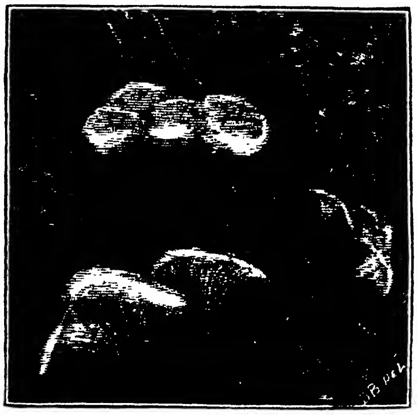

Fig. 4.—A Phosphorescent Mushroom (*Agaricus olearius*).

There are a great many substances which are phosphorescent after insolation besides the sulphide of calcium, or Canton's phosphorus, as it is commonly called, which forms the basis of Balmain's paint. When the card is no longer luminous in the dark, take it into the sunshine again for a few minutes, and have resting on the paint some object—as, *e.g.*, a penny-piece. Upon taking the card into the dark cellar once more, it will be found that there is this time a dark, immutable, and immovable shadow surrounded by a luminous surface. The paint may likewise be excited by holding it close to a gas-light, but it will be found that after a few experiments the paint has lost its phosphorescent property, owing to the absorption of the heat rays. This antagonism of the heat radiations to the manifestation of phosphorescence after insolation was known more than a century ago, Wilson having in 1775 pointed out that the rays of the violet end of the spectrum, where there is least heat, cause a vivid phosphorescence in the sulphide of calcium, while the rays at the red end, where there is most heat, cause the phosphorescence produced by the other rays to cease. The phosphorescent sulphide of calcium was prepared by Canton by heating intensely for one hour a mixture of three parts of sifted calcined oyster-shells with one part of sulphur, which is materially the same as the plan adopted by Balmain, who heats together lime and sulphur, and the product is then for painting purposes mixed with mastic varnish and a little turpentine. The nature of the light emitted varies with the method employed to prepare the sulphide, an orange-coloured phosphorescence being obtained from sulphide of calcium which has been prepared from oyster shells, while the light is much more refrangible, bluish, when the sulphide is made from carbonate of lime which has been precipitated.

Among the other substances which become phosphorescent by insolation we may mention the diamond, and the following salts of lime—the nitrate, carbonate, phosphate, and arseniate. The sulphide of barium is likewise a remarkable phosphorescent body, and is said to have been the first substance that was known to become phosphorescent after insolation. It is variously known as solar phosphorus, Bologna stone, or Bologna phosphorus, and may be made in the following manner:—Mix the finely-powdered heavy spar or sulphate with gum, and calcine the paste thus obtained. The product of calcination is the sulphide of barium.

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* A more complete account of the luminosity of plants will be found in Brown's "Manual of Botany," pp. 593-7.

The length of time during which a substance continues to phosphoresce after insolation varies with its nature, as one would expect, and while some give out light for hours, others do not exhibit it even after the lapse of a second. Becquerel found, for example, that fluor-spar is seen to be phosphorescent only when not more than $\frac{1}{1000}$th of a second has passed since it was insolated. For such delicate determinations of duration, he employed the phosphoroscope. The body to be experimented upon is placed in a cell within the instrument, and between two discs which are made to revolve (Fig. 5). Each disc may have one or more sectorial apertures which are not opposite to another, so that upon turning the handle when there is nothing in the phosphoroscope the observer sees no light coming from the aperture next to, and passing his eye. When, however, a phosphorescent substance is in the cell, it receives a charge of light, if one may so speak, as the aperture in the disc farthest from the observer passes it, and if the light it emits after this sudden and short insolation last for a small fraction of a second, the observer on the other side sees it when the aperture in the disc nearest to him passes his eye.

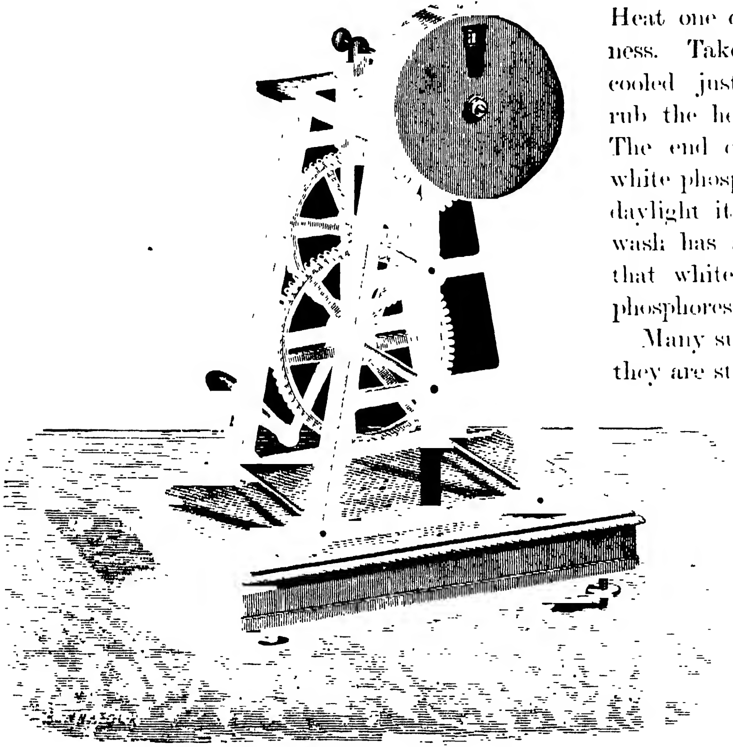
Fig 5.—Becquerel's Phosphoroscope.

Heat alone will produce phosphorescence in some bodies, and one of the most remarkable in this respect is the fluor-spar, or fluoride of calcium, which we have just seen is so weakly phosphorescent after insolation. If powdered fluor-spar be put on a plate of heated iron, not hot enough to be red, the powder will shine with a vivid phosphoric light. And a variety of the fluor-spar, called *chlorophane*, emits light at a temperature so low as 20° to 25° C. In illustration of this portion of our subject, the reader may try the following interesting and simple experiment. Heat one of the fire-irons, say the poker, to redness. Take it now into the cellar, and when it has cooled just sufficiently to emit no further light, rub the heated end over the whitewashed wall. The end of the poker is now illuminated by a white phosphoric light, and upon bringing it into daylight it will be seen that some of the whitewash has adhered to the iron. It is remarkable that whitewash is also said to be very faintly phosphorescent after insolation.

Many substances emit a phosphoric light when they are struck in the dark, and among these are chlorate of potash, felspar, and sugar. Take two pieces of lump sugar into a dark room and strike them together. Every now and again faint flashes of light will be observed, thus furnishing us with a simple example of phosphorescence produced by percussion.

We have now to describe the remarkable cases of phosphorescence to be seen in empty space, under circumstances that have been discovered by Mr. Crookes. When discussing this subject,* we described the various phenomena, mechanical, electrical, and physiological, which may be observed within a vacuous chamber; and we may take it as a sign of the times that this account has become partially incomplete even so soon, owing to the discoveries that have been made since it was written. We then learnt that a fairly good vacuum transmits an electric spark, that in a still better vacuum, well-balanced and very light bodies begin to move when the sun's rays fall on them. But we are now taught, in addition, that when the vacuum has been made so perfect that there is within the vacuous vessel a pressure of only about one millionth of an atmosphere, extraordinary phosphorescent phenomena are observed if the vessel be connected with an induction coil. At such a pressure the inner surface of the glass glows with a rich light, whose colour, Crookes has shown, depends upon the nature of the glass vessel used: uranium glass giving a dark green phosphorescence, English glass a blue, and soft German glass a bright apple-green phosphorescence. The particular point of emptiness at which this happens will, perhaps, be still better understood by turning to Fig. 15, p. 110, Vol. I., where an induction spark is represented as passing through an empty vessel (c), accompanied by that layer-like appearance which is known as the stratification of the electric light. If this vessel (c) could be made more empty of air still, the stratifications would disappear, and then would flash out all along the surface of the glass the peculiar phosphorescence which we are considering. Crookes regards this phosphorescence as produced by the bombardment of the remaining molecules of gas against the sides of the glass, and his experiments would appear to show that these molecules are shot off the negative pole in straight lines, like rays of light. Many minerals placed in the path of the flying molecules exhibit a brilliant phosphorescence. A diamond, for example, that was mounted in the centre of an exhausted bulb (Fig. 6) shone with as much light as a candle, phosphorescing with a bright green light when the negative discharge was directed on to it. A collection of diamonds, lent to Crookes by Professor Maskelyne, exhibited, when treated in the same manner, the following colours of phosphorescence: apricot, red, orange, yellowish-green, pale-green, and blue. Under similar circumstances, rubies shine with a brilliant rich red colour, as if they are glowing hot, and they emit this colour of phosphorescent light whatever may be their natural colour.

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* "Empty Space," "Science for All," Vol. I., p. 110.

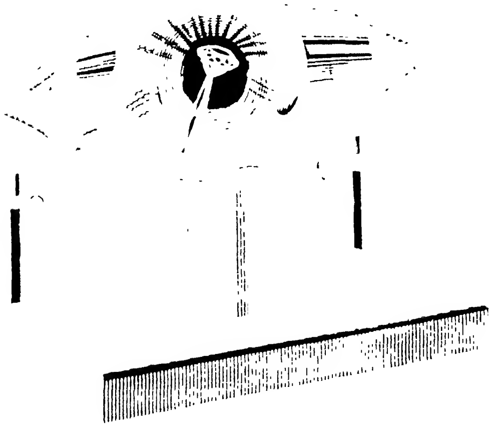

Fig. 6.—A Phosphorescent Diamond.

Many other curious facts were discovered in this investigation, and not the least important of these was that a sort of shadow is produced by an obstructing body placed in the path of the rushing molecules. Within a pear-shaped bulb (Fig. 7) subsequently exhausted to the proper degree, there was placed a cross (*b*) so that it would be in the way of air particles rushing from the negative pole (*a*), when the apparatus was joined up to the induction coil. Under the influence of the air particles flying from *a*, all parts of the bulb, save a cross-shaped space at the broad end, soon exhibited a phosphorescent light presenting the appearance given at *c d* (Fig. 8). Upon now shaking the aluminium cross, *b*, (Fig. 7) off its hinge, the perfectly fresh dark space at *c d* became luminous under the bombardment of the air particles, and so luminous in comparison with the wearied background that had been phosphorescing from the commencement, that now the observer beheld a luminous cross on a comparatively black ground (*e f*, Fig. 8). We see, therefore, that the negatively electrified molecules of air remaining in the bulb dash against anything that is in front, and cast shadows, as it were, of obstacles which stand in their way; that, where

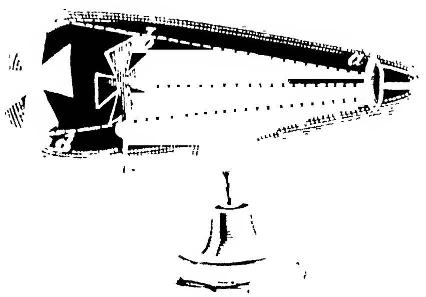

Fig. 7.—A Shadow on a Phosphorescent Ground.

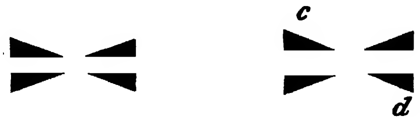

Fig. 8.—Reversal of the Shadow.

they are stopped by the glass, light is produced by the sudden arrest of velocity, and we may further add that it is accompanied by a rise of temperature.

We have now one more example of phosphorescence to consider, and then we have done, and it is that of the phosphorus with which we started. Perhaps in none of the other cases we have mentioned can it be positively said that combustion is going on, but in this there is no doubt. Phosphorus very readily combines with the oxygen of the air, *i.e.*, in ordinary language, it readily burns, and when it burns it gives out light. If it be burning fiercely it will give out a light that may dazzle the eyes, and the higher oxide of phosphorus will be formed. If, on the other hand, it be burning very slowly, the lower oxide is formed, and only a very faint light is emitted. It will therefore be seen that the phosphorescence of the match-track is due to the combustion of the trace of phosphorus left on it, the friction of the operation raising its temperature sufficiently to make it burn in the air.*

We have seen, then, in the course of this paper, that there are many substances—animal, vegetable, and mineral—which, under certain circumstances, are self-luminous, emitting a faint light. Now, to produce this light there must be a molecular agitation of some sort sufficient to disturb the ether, and originate those ether waves which we suppose to be the basis of light, and this molecular disturbance may arise from chemical or physical changes. Where chemical change is the cause of phosphorescence new compounds are formed, as in the combustion of phosphorus, and perhaps also in the cases of decay and putrefaction we have had occasion to mention; for here there must be such alterations of atomic position, both preceding, as preparatory to, and during decomposition, that it requires no stretch of imagination to see that the ether that laves these atoms may be sufficiently disturbed to produce light. Nor is it difficult to picture to ourselves what may be happening where phosphorescence arises from physical causes, for here the necessary vibration, or trembling of the phosphorescent body's molecules may be produced by the beating of air particles against it, as in the phenomena Crookes has so successfully studied, or by the wash of ether waves, as in the case of insolation.

Turning from matters theoretical to those practical, we cannot say as yet that phosphorescence has been utilised in the affairs of life. It has, however, been proposed to use Balmain's luminous paint for painting the interiors of railway carriages, among other purposes, to the end that the phosphorescent mixture, after drinking in the sunbeams falling athwart the rushing train, might give them out again in dark tunnels for the benefit of passengers. The white man is, in short, treading in the steps of his red brother, who has for long been known to utilise the light of the wah-wah-taysee—attached to his hands and feet for night-travelling, and within his home for the benefit of his industrious squaw performing her evening wigwam duties.

THE BIOGRAPHY OF A TRILOBITE.

By Charles Callaway, M.A., D.Sc., F.G.S.

On examining some of the older rocks, or, in default of going to the fountain-head of knowledge, almost any general geological collections, some curious-looking petrifactions like those figured on pp. 54, 55, 56, will soon strike the eye. On further extending his acquaintance with the extinct orders of beings known as fossils, the student will note that the "Trilobite," as he will learn to call the forms which first attracted his attention, though they have all one general family likeness, differ in numerous minor particulars, and that it is owing to these differences that each form has got a different name. The Trilobite, if questioned by the student, might indeed tell its own history, not orally, but in the way in which even an inanimate object can address the practised interrogator. Hence, we may imagine such a fossil relating to us in brief form the story of its life in the early waters, and its entire disappearance eons and eons ago. This tale would be briefly as follows :—

It was born in the Carboniferous epoch. Its home was in the soft calcareous mud at the bottom of a shallow sea. By the dim light which found its way down through the water, it could see thousands of creatures like itself crawling over the surface of the mud, while over its head swam great shark-like fishes, and strange monsters, shaped like huge nautili straightened out, floated on the waves, and spread out their feelers in search of prey. Its mother, had she possessed the gift of speech, might have told tales about the land which bordered upon the ocean in which their ancestors lived*—how the land was overspread with great ferns, gigantic club mosses, horse-tails thirty feet high, and wonderful trees, whose tall trunks were covered over with seal-like scars. She might also have described the strange spiders and insects which inhabited the forests, and deplored the dulness of the scenery attributable to the fact that butterflies and flowers had not yet come into being. If she were endowed with prophetic instinct she could have foretold that the race was doomed to extinction, and that when the last Carboniferous tree-fern had faded, the order of the Trilobites would cease to be. Their place would then be occupied by the *Prestwichia*, an animal (Fig. 1) intermediate in form between themselves and a king-crab; and then in after-ages, the noble king-crab himself (Fig. 2) would represent their order.

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* "Striking a Light," "Science for All," Vol. I., p. 140.

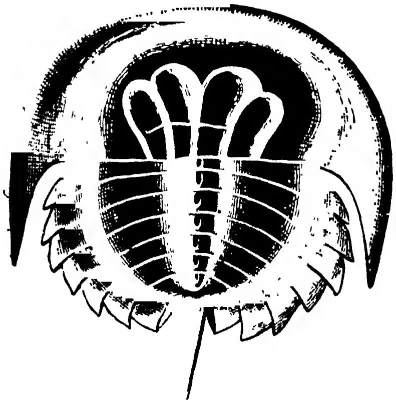
Fig. 1.—Prestwichia, Coal Measures.

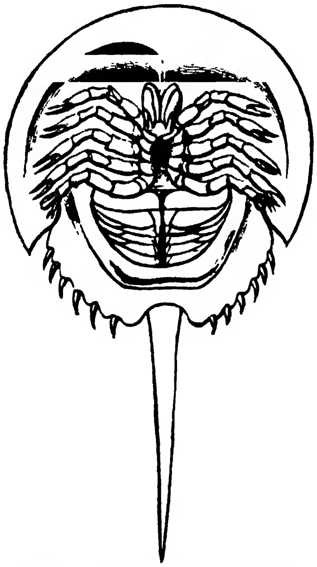
Fig. 2.—Under Surface of King-Crab. (*Limulus polyphemus*).

The Trilobites are a very ancient race. They existed in a finely-developed condition in the oldest Cambrian† epoch, they reached their culmination in Silurian times, their numbers had greatly diminished by the Devonian period, and in the Carboniferous epoch exceeded not more than about a dozen species. Though their numbers were small, they had not degenerated either in beauty or in the complexity of their organisation. Indeed; there is reason to believe that they were superior in these respects to most of the Cambrian Trilobites, and to many of their Silurian descendants.

But first of all we must describe what a Trilobite is like. Its body is divided into three lobes—hence its name—a peculiarity in which it is imitated by the *Prestwichia*. The central lobe is called the *axis*, and the parts of the body are symmetrically arranged on each side. Taking a Trilobite from front to back, trilobation is also seen. The three parts are the *head*, the *thorax*, and the *tail*.

Fig. 3 shows the upper surface of the head. The central lobe is called the *glabella* (A), and it is separated from the *cheeks* on each side by the *axail furrows* (A*). At the base of the glabella is the *neck-lobe* (*b*), separated by the *neck-furrow* (*c*). The glabella is also lobed (*g*, *h*, *i*) at the side, and the side-lobes are separated by furrows (*d*, *e*, *f*). In front is the *frontal lobe* (*a*), which is sometimes interrupted by a pair of frontal furrows (*f**). Forming one mass with the glabella are portions of the cheeks (B, *j*, *r*, *k*). This central head-shield is bounded on each side by a curved line called the *facial suture* (*q*, *q*). A part of each cheek is movable or free. These *free cheeks* (*o* C) bear the *eyes*, which in the figure are compound. The posterior angle (B) is often produced into spines. The facial suture sometimes cuts the posterior margin, as seen

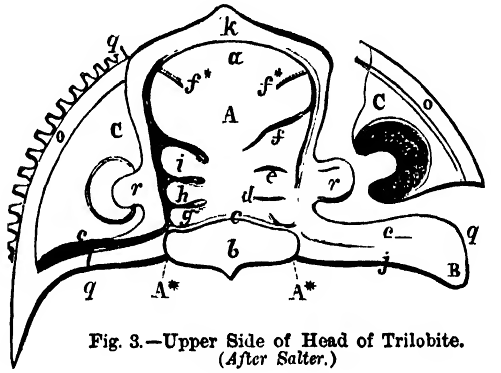

Fig. 3.—Upper Side of Head of Trilobite. (*After Salter.*)

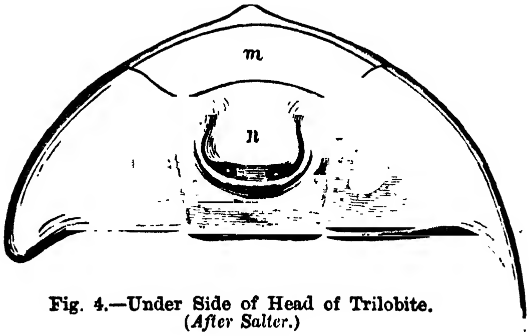

Fig. 4.—Under Side of Head of Trilobite. (*After Salter.*)

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[*] "Science for All," Vol. III., p. 48.

[†] "Science for All," Vol. I., Frontispiece.

in the left side of the head; but in other types it turns round at a right angle, and cuts the side margin, as represented in the right side. The under surface of the head is shown in Fig. 4. The *rostral shield* is seen at *m*, and the *labrum* at *n*. The *thorax* is made up of segments, or *thorax-rings* (Fig. 5), which vary in number from two to twenty-six. Each ring consists of an axis (A), with *pleuræ* on each side. The pleuræ are sometimes faceted (*a*) to enable them to slide over each other, when the animal rolls itself up. In other cases, the pleuræ end in points (*g*, *g*). The tail, or *pygidium*, is in one piece (Fig. 6). A is the axis. The lateral portions are marked so as to represent distinct segments. The margin (*e*) is sometimes entire (*a* *), sometimes it is produced into points (*b* *). In these figures the general characters of Trilobites are represented, not any one species, as must already have been evident from the dissimilarity of the opposite sides of the body. What is their place in the animal creation? The Trilobites' bodies, being covered with a chitinous—or horny—shell or "crust," and being articulated in a number of segments, it is evident that they belong to the class *Crustacea*, of which crabs, lobsters, shrimps, king-crabs, barnacles, and wood-lice are examples. But they differ widely from all other crustaceans. They are probably nearest to the wood-louse, for that disagreeable creature has, like them, compound eyes and a broad tail-shield, while it also possesses the power of rolling itself into a ball. But the wood-louse order has always seven segments to the body, no more and no less, and some of its number live entirely on the land. The Trilobites are still less like the king-crab, for they very rarely possess any appendage to the body. On the whole, they are entitled to the rank of a distinct order, the *Trilobita*.

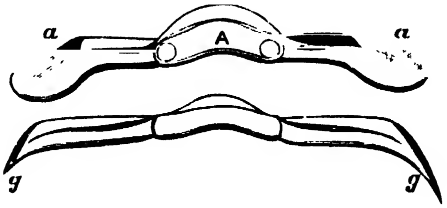

Fig. 5.—Two Segments of a Trilobite. (*After Salter.*)

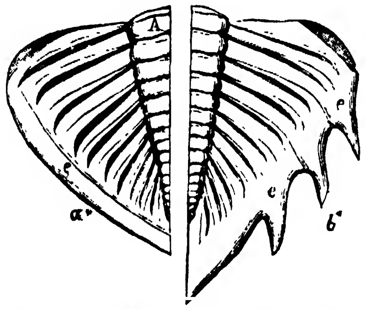

Fig. 6.—Tail of Trilobite. (*After Salter.*)

It will, however, have been noticed that we have compared the race with creatures which did not come into being until long after its extinction.

In our wanderings over the upturned sea bottoms, we often visit the grave-yards of ancient Trilobites. These burial-places were of very different antiquity. First of all, races of Trilobites flourished in the Cambrian epoch. At their death, the soft portions of their bodies, such as their breathing organs, their swimming feet, and their internal parts, perished by decomposition, while their hard shell or carapace was buried in the soft mud. Bed upon bed of this mud was deposited, each containing the remains of the races peculiar to the period. All the grave-yards of the Cambrian epoch alone reached a thickness of several thousands of feet. In like manner, the Silurian periods, Lower and Upper, witnessed the accumulation of great thicknesses of strata of mud, sandstone, and limestone, containing the carapaces of many families, most of which differed from their Cambrian ancestors. Then followed the Devonian epoch, with like deposits of Trilobite-bearing strata.

But some one may perhaps inquire how we can see the remains of Cambrian Trilobites, when the Cambrian burial-grounds are covered in by the deposits of later periods. The reply to the question is not difficult. The reader must know that at the close of the Lower Silurian (Ordovician) epoch, the preceding strata were bent into great folds, and were gradually lifted up to the level of the sea,* and the waves, wearing away the tops of the curves, exposed one after another the underlying beds. In like manner, the burial-grounds of other periods are exposed to after ages by upheaval of one set of strata, and the washing or wearing away of another series. In this way, by visiting different areas, we are able in one place to study Cambrian Trilobites, in another Silurian, and in a third Devonian.

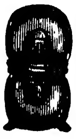

Fig. 7.—Agnostus

In the most ancient of the Cambrian grave-yards may be noticed a very curious Trilobite, which seems very inferior to ordinary Trilobites in its organisation (Fig. 7). It had no eyes or facial suture. The head and tail were almost alike, and there were only two segments in the thorax. But all of these ancient creatures are not so simply constructed. Associated with this *Agnostus* was one of the most magnificent of the Trilobites (Fig. 8). It was

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* "Science for All," Vol. II., pp. 163—165.

of great size, sometimes reaching a length of two feet. The cheeks were produced into great spines, and the pleuræ also ended in spines. The segments of the thorax were numerous, and the compound eyes very large. These strange creatures are regarded as amongst the earliest of the order, and wherever they are found, the strata containing them are considered very ancient.

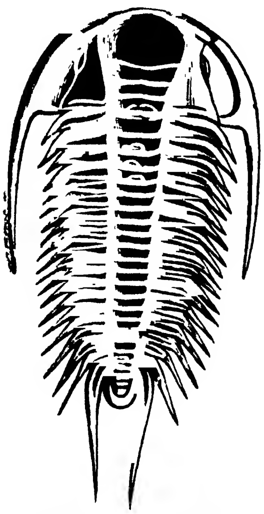
Fig. 8.—Paradoxides.

In the Ordovician grave-yards are found the remains, of some very curious Trilobites. Of these the *Trinucleus* (Fig. 9) was perhaps the most interesting. The head was large, and the cheek spines projected behind sometimes to double the length of the body. In the centre of the head were three prominent lobes, which were surrounded by a broad fringe curiously dotted all over. The thorax was of six segments, and the tail small.

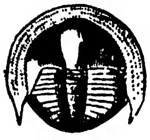
Fig. 9.—Trinucleus.

In Silurian times, Trilobites were very handsome in form and very numerous. They might be regarded as then monarchs of the ocean bed. Some of them were of very fantastic shape, the glabella swelling out into a prominent ball, and the thorax and tail being ornamented with numerous spines. In fact, they seemed to be all knobs and spikes. But as the race dwindled away in the Devonian and Lower Carboniferous periods, the aberrant forms vanished from the scene, and the Trilobites became more sober-looking creatures.

Their ancestors were never very particular in their burial rites—albeit they had little "local option" as to their graves. Some of them were entombed in proper fashion, lying at full length without distortion or fracture. But others died curled up into a ball, and so were buried. When we light upon them in their grave-yards, we find them in the same attitude, their tails bent round so as nearly to touch the front of the head. Great numbers were buried in fragments. In some localities, we find heads predominating, and in others, tails. We sometimes discover all the parts in the same spot, but slightly moved away from each other. Their bodies had evidently lain on the surface of the mud at the sea-bottom till all the soft parts had decayed. The different parts and segments thus became detached. Then gentle currents in the water slightly moved the loosened pieces; but, before the disturbance had been carried far, more mud was deposited, the carapace was covered in, and the position of its parts was finally fixed.

It is certain that the mode of life of Trilobites of even the most ancient epochs was similar to that of the most modern. They lived in a shallow sea, otherwise the light of the sun could not reach them. The Lower Cambrian forms must also have enjoyed the advantages of light, for, though *Agnostus* was blind, *Paradoxides* had large compound eyes, and one may be quite certain that he would not have been endowed with useless organs. In many of the race the eyes are simple, and in a few they were mounted on short stalks.

We sometimes find in the grave-yards very small creatures which at first greatly puzzle us; but after a time we ascertain they are the carapaces of very young Trilobites. Either the little things had died in their infancy, or they had cast their carapace in the process of growth. The one which we have figured was very simple (Fig. 10) in structure, consisting of a minute oval shield, on which were marked an elongated smooth glabella, and two or three thorax-rings. There was as yet no separation into head, thorax, and tail, though the specimen was the young of a highly organised Trilobite (*Conocoryphe*).

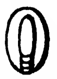
Fig. 10. Infant Trilobite.

While studying some of the Cambrian burial-grounds, where the rock in which the Trilobites were entombed was a cleaved slate, we may observe that many of the specimens were distorted. Some were squeezed sideways, so as to lengthen them out, others were made short and broad, while some were squeezed obliquely,* so as to give them a high-shouldered appearance.

But though some Trilobites died out early and others late, the carapace of the latest races became embedded in a calcareous mud, which by-and-by was consolidated into the Carboniferous limestone. By changes in the geography of the globe, sand and mud were deposited on its burial-place, and the sea was filled in, and became dry land, on which grew the luxuriant vegetation of the Coal Measures. Then the sceptre departed from the Trilobites, and the dominion of the sea-bottom passed to other races.

When, in later ages, subsidence took place, and the sea again covered in the land, great swimming reptiles* held the sovereignty of the sea. These, like the Trilobites, culminated, dwindled away, and passed into extinction, leaving only their bones to tell future epochs of their existence. Meanwhile the higher races of the world came into being on the land, and the rule of marine animals passed away. In process of time, Man claimed the sceptre of the world. Without carapace, compound eyes, facial suture, or glabella, he became the summit of creation, and the final and permanent end of the universal plan. In his thirst for knowledge, he has delved into the earth's crust, and explored the ancient grave-yards of Trilobite, Coccosteus, and Plesiosaurus alike. He writes books upon their structure and history, and describes them as an inferior creation. But in his blindness he fails to foresee that his proud race, like their humble one, may pass away, and that still higher orders of life may possibly come into existence, who will describe a man as Man describes a Trilobite.

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* "Science for All," Vol. I., p. 346.

SEA-SQUIRTS.

By Dr. Andrew Wilson, F.R.S.E.

THE animals whose name heads this paper cannot claim a close or intimate acquaintance with the public at large, inasmuch as their very existence is unknown to, and undreamt of by all save those to whom the chief facts of zoology are tolerably familiar. Nor, for that matter, are the sea-squirts externally captivating beings. Regarded from their outward aspect, they may be said to be more than plain; and the term "ugly" may, without much offence even to the scientific mind—accustomed to perceive beauty where commonplace vision beholds none—be applied to the animals in question (Fig. 1). That they are animals at all might be subject of doubt with not a few observers beholding a sea-squirt for the first time. There is nothing to suggest ordinary animality in the figure and guise of a being whose outward appearance may readily enough be described by saying that it exactly resembles the "leather bottel" of the song, in that it possesses a bag or sac-like body (Fig. 1, A, B), with two openings; the said body, being attached to a stone, or more commonly, perhaps, to an oyster-shell, or similar object. In zoological works, the term "double-necked jar" is used to describe the form and appearance of the common "sea-squirts." The technical name *Ascidian* applied to the familiar forms, is, in fact, derived from the Greek *askos*, meaning a wine-skin, which, as formed of old—and as made in the East to-day—from the skin or stomach of some animal, presents a shape very nearly resembling that into which Nature modelled the sea-squirts ages before man, or his necessities in the way of wine-skins, were facts of the universe. "Sea-squirts" to the popular mind, then, may not at first sight appear to present a subject of interest, even for casual study. But promise of intellectual gain, like the harvest of important chemical products gained from waste matters, may not be judged or estimated by the external appearances of things. And the history of the sea-squirts offers an illustration in support of this allegation. Not merely may we discover a veritable mine of zoological wealth within the compass of a sea-squirt's frame, but we may likewise discover that through recent research and its speculative philosophy, the sea-squirt race becomes theoretically connected with even the highest forms of animal life. For in that system of hypothetic philosophy whch makes much of evolution and descent, the young sea-squirt becomes the parent stock of the Vertebrate animals — a fact well-known to all readers who have dipped even cursorily into the recent literature of zoology.

But leaving on one side all questions of what sea-squirts may have been, we may find more than enough to interest us in what they at present are; and more than one important scientific truth may be wrought out, and thought out, if, first of all, we endeavour to understand the comparatively simple structure of the "leather bottel" of the natural historian.

On an oyster-shell, then, we have found, attached by its base or lower extremity, a tolerably clear bag-like organism, about an inch in length. Despite its clearness it is of tough consistence, and can be handled without much fear of destroying its form or substance. At its upper end we see two apertures, borne each on a slight neck or elevation. The higher of the two we shall name the "mouth," whilst the lower has been termed the "atrial aperture." We shall find an advantage in fixing these names once for all on our minds, inasmuch as an appreciation of the relative situation and function of these openings lies at the root of the understanding of a large portion of the sea-squirt structure. There is something remarkable in the first instance to be noted regarding the bag or sac, or outer layer, within which sea-squirt anatomy conceals its identity. The tough outer layer of the body is called the "tunic," or "test" (Fig. 2, *d*)—which latter term, it may be remarked, is often applied to the "shells" of such animals as the sea urchins,* and of other and lower forms of animal life as well. When chemically analysed this outer layer is found to contain a substance called *cellulose*, almost identical in its composition with starch.

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* "Science for All," Vol. II., p. 137.

The discovery of this fact was, as has been well remarked, one of the most remarkable achievements of comparative physiology. Why? it may be asked. The answer is not difficult to find. Cellulose is a substance of world-wide occurrence in the *vegetable* kingdom. It is found alike in low and high *plants.* The lichen possesses it as well as the oak, and it is found alike in the fungus and in the palm. A substance like this, then, is characteristically a plant-product. Its discovery in an *animal* was therefore a notable fact for science; and although we now know that a most confusing identity of substance and form besets animal and plant worlds, still the fact of cellulose being manufactured by animals stands out clearly as one of the best examples of this interchange of secreting powers. The occurrence of cellulose in a sea-squirt is, in truth, an infringement of the presumed "patent right" of the plant to produce this substance; but so many cases of allied nature occur in the experience of the biologist, that, as in law, so in natural history, precedents and custom convert an unusual into a perfectly normal condition of life.

If, in examining our sea-squirt, we lay open the tough "tunic," or "test"—from the presence of which the sea-squirts' family designation of "Tunicates" is derived—we shall find internally, to this layer, a second and more delicate coating. The latter is named the "mantle" (Fig. 2, *e*). In its general nature it is highly muscular, and to its action may be ascribed the popular name of "sea-squirts" which the Tunicates have received. When a living sea-squirt is touched, or roughly handled, *jets d'eau* are immediately expelled from the two orifices of its sac-like body, but in greatest quantity from the mouth aperture. This fluid is the water used in breathing, and the forcible contraction of the body is due to the action of the "mantle," which thus, by the energetic powers with which it is endowed, seems in a measure to compensate for the otherwise stationary and fixed habits of these beings.

The mouth of higher animals leads into various channels, amongst others into the breathing and digestive systems; and it is the most natural of expectations that this aperture should lead into the throat, and thence into the stomach of the animal form. When, taking a sea-squirt in hand, we anatomically investigate its structure, we may feel surprised to find that instead of the mouth introducing us to the digestive system of the animal, it leads into a sac or bag (Fig. 2, *c*), which, in common sea-squirts, is relatively large when compared with the size of the animal itself. In a common sea-squirt, at present before me, the length of the body is one and a half inches, and the sac in question is three-quarters of an inch long by half an inch broad. When we scan closely the surface of this bag, we find it to present a texture somewhat resembling very fine-meshed muslin in appearance. The walls of this bag, in fact, resemble a fine lattice, and the sac itself opens below into a tube which we have little difficulty in discovering to be the beginning of the digestive system proper. Now what is this sac or bag into which the mouth-opening of our sea-squirt leads? The microscopic examination of the sac shows that it consists of a dense net-work of blood-vessels, lodged within the substance of its lattice-like folds, and also that the meshes of the lattice-work are fringed with those delicate ever-moving filaments named *cilia*, which occur in our own windpipes, and in other parts of our frame.† So that we find, firstly, that whatever be its functions, this sac receives a large supply of sea-squirt blood, which circulates through the lattice-work structure; and secondly, that its cilia will ensure the constant circulation of whatever fluids are admitted to its interior.

But, side by side with this first or *branchial sac* (as we may name the lattice-work bag into which the sea-squirt's mouth opens) another sac or bag (Fig. 2, *l*) is readily discovered, and the use of sac number one can only be rightly appreciated when the nature of bag number two has also been investigated. The walls of this second sac do not present the lattice-work arrangement seen in the "branchial bag," nor is its substance beset with blood-vessels like that of the latter organ. Furthermore, we can readily discover that just as the mouth leads into the branchial sac, so the atrial or other orifice of the sea-squirt's body leads *from* the second sac, which may therefore be called the *atrial sac* or *atrium.* We say *from* the atrial sac, because, as the sequel will show, the second aperture (Fig. 2, *m*), is in reality an aperture of exit, just as the mouth, on the contrary, is an entrance to the sea-squirt economy. In the living sea-squirt continuous currents of water pass into the branchial sac through the mouth. These currents remind us of the similar arrangement familiar to all in the mouth of fishes, into which water is continually received, and passed into the gill-chambers to provide the oxygen necessary to aërate the blood. In sea-squirt physiology, the same purpose is served by the in-going water-currents of the branchial sac. Laden with the vitalising oxygen, these currents serve to purify the blood of the sea-squirt, whilst the effete carbonic acid gas and other waste products are given off from the blood to the water, which thus becomes an effete and useless product within the sea-squirt domain. Thus it is noteworthy, that humble though the sea-squirt may appear to be in the zoological world, its vital processes partake of the same nature as our own; the excretion of carbonic acid and the inhalation or absorption of oxygen being as characteristic a feature of Tunicate life as of animal and human existence.

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* "A Starfish," "Science for All," Vol. III., p. 299.

† "Science for All," Vol. III., p. 324.

In the common fishes, the effete water of respiration or breathing is—as everybody knows who has watched a gold fish breathe—forced out behind the gill-covers by the forcible contraction of these structures. We have seen that our sea-squirt also possesses the means for forcibly ejecting its breathing-water in the sharp contraction of the "mantle" or inner and muscular lining of its body. But such a forcible method of ejecting water would hardly suit the ordinary run of Tunicate existence. To begin with, it would demand a too great exercise of muscular power, and nature is rarely if ever found on the side of wasteful expenditure, when quieter methods of action exist. Hence we find, in the incessant play of the *cilia* which line the meshes of the branchial sac, the means for not merely sweeping from without its precincts the effete water, but likewise for renewing the salutary and vivifying supply. The cilia work incessantly in the direction of the atrial sac, which we have noted to be side by side with the branchial one—or which, as some authorities maintain, actually surrounds and encloses the branchial bag—and from the atrial aperture the effete currents are in due course discharged into the world of waters outside. Thus in the living sea-squirt constant currents of water flow into the body by the mouth, and as incessant streams escape by the atrial orifice. The water, in its passage from one sac to the other, performs the double duty of giving up the oxygen it carries for the purification of the animal's blood, and of serving to carry off the effete and waste products which the act of living entails alike in sea squirt and in man. The breathing sac of the former is in truth analogous to the lungs of the latter; and it is noteworthy that in the lowest fish and vertebrate—the little clear-bodied Lancelet (*Amphioxus*) an arrangement for breathing exists, similar to the perforated branchial sac of the sea-squirt. In concluding our examination of the sea-squirt's breathing organs, we may lastly note that in certain Tunicates, which differ from the common fixed forms in that they swim freely on the surface of the sea, the inhalation and ejection of water are used as a means of locomotion, very much as in the case of the cuttle-fish.

The branchial sac with which our examination of the sea-squirt began, may serve as a text for investigation in another direction into Tunicate existence. Just within the mouth-opening of this sac, we find a circlet of small tentacles (Fig. 2, *b*), probably serving as organs of touch, and, in any case, guarding, like sentinels, the aperture of the mouth, which can be firmly closed, should occasion require, by the muscular fibres around its margin. In its fixed condition, a common Tunicate cannot, even by the biassed zoological mind, be regarded as—to use a popular and expressive phrase—"a lively animal." The need for acute and active appreciation of what is going on in the world around it, which is a condition of existence in the higher actively moving animals, is not felt or experienced in sea-squirt life. Yet organs of sense are by no means unknown, in addition to the tentacles or feelers placed just within the mouth-opening. For instance, we find that in the young stage of sea-squirts, eyes exist; and in the mature Tunicate we may discover around the mouth-opening, and sometimes within the atrial aperture also, a series of small colour specks, which are undoubtedly rudimentary organs of sight. We also know of a simple organ of hearing which exists in some of these animals, and which exhibits as its essential features, the form of a little sac or bag containing fluid, in addition to a limy particle (or *otolith*)—such being the common beginnings of ears in the lower animals generally. A groove provided with cilia, and placed near the branchial sac, is credited with being an organ of smell. The possession of sense organs, however, indicates the presence of a nervous system, or its equivalent. "What," it may be asked, "and where, is the nervous system of the sea-squirt?" Just between the two apertures of the jar-shaped body, we find the internal structure of the sea-squirt to exhibit a mass of nervous matter (Fig. 2, *n*), called—as nerve-masses are everywhere in the animal world—a *ganglion.* From this nerve-mass, as from a centre, nerves are distributed to the body at large. The muscular mantle, in particular, receives a large supply of nerves; and thus when a sea-squirt ejects its breathing water in the face of a prying zoologist, it is highly probable that the act is essentially similar in its details to that whereby the assaulted person is enabled to withdraw from sea-squirt society. In the former case, a touch communicated to the body was sent as a nervous impulse to the nerve-mass, and hence was "reflected," as we say, to the nerves of the mantle, with the result already detailed. And so also in the case of the human observer. A jet of water received in the face communicates a sensation to the chief nerve-centre, or brain, which, "reflecting" its sensation in its turn to the muscular arrangements of the legs, carries the assaulted to safe distance, or, it may be, under other circumstances, is "reflected" back upon the sea-squirt itself, and serves to diffuse zoological "sweetness and light" into the scientific examination of that organism.

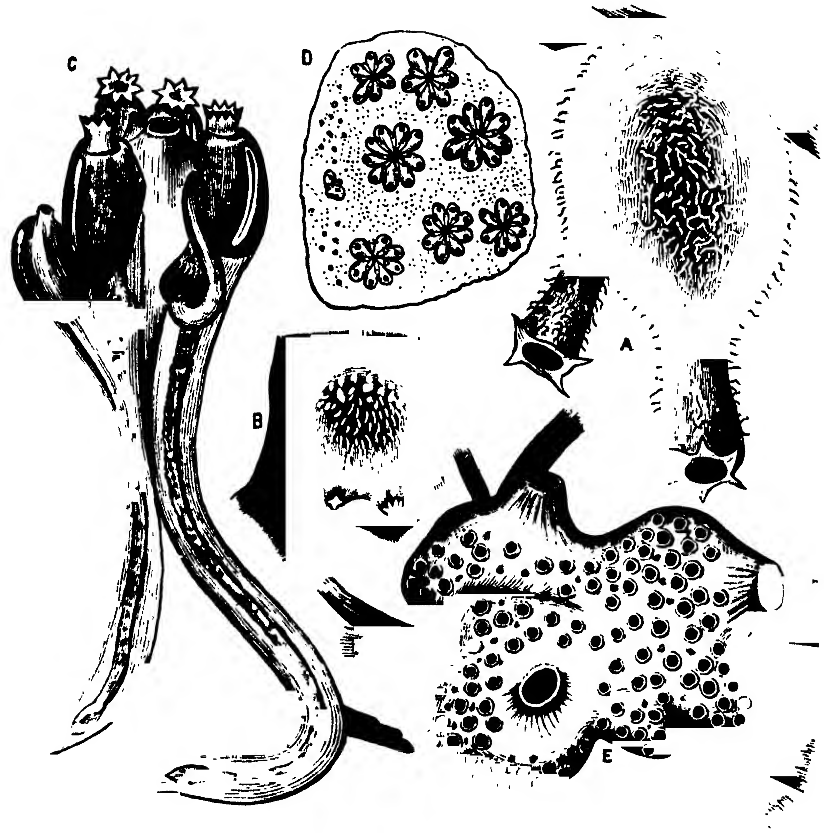

Fig. 1.—Various Kinds of Sea-squirts. (*After Lacaze-Duthiers.*)
A, Molgula socialis; B, Amurella simplex; C, Circinalium concrescens, a social Ascidian; D, Botryllus calendula, a compound Sea-squirt; E, Astellium spongiforme, also compound.

Sea-squirts, however, like all other living beings, possess a commissariat department wherewith the wants of the frame are supplied, and the ends of nutrition subserved. The free, actively moving animal is at no loss to provide for its wants, and in general is adapted by nature to forage successfully and advantageously. But the fixed sea-squirt, with a digestive system removed to its internal parts, so to speak, and whose true throat begins only at the bottom of the branchial sac, might, and not unreasonably, be deemed to be in evil case as regards its food-providing habits. The difficulties of Tunicate life in this respect are, however, fairly and well overcome by an ingenious—if one may apply that term to Nature—arrangement connected with the branchial sac itself. On one side of this sac a row of little tongue-like processes, called "languettes," project into its cavity. The function of these bodies is supposed to be that of straining off solid matters from the water which flows into the sac, such matters being passed downwards to the opening of the throat at the bottom of that structure. Thus, sea-squirt fare is conveyed into the economy along with the water used in breathing. The digestive apparatus is tolerably complete. The throat expands into a stomach (Fig. 2, *g*), and this organ is continued into an intestine (Fig. 2, *h*) which terminates the atrial sac itself; but there is no distinct liver, such as we should expect to find in higher animals. Blood, manufactured from the digested food, has, in all animals, the function of nourishing the body. In the sea-squirts, the blood is therefore intended to nourish the tissues, and for that purpose is circulated and propelled, as in higher animals, by a central engine—the *heart.* Now, in the higher animals—birds and quadrupeds—the heart has a distinctly double function. It sends blood through the body, and at the same time propels that fluid to the lungs for purification. To effect this end, we find that such a heart is in reality a double organ. It is so in every bird and every quadruped. It consists of a right side, which propels blood to the lungs, whence the blood is returned to the left side of the heart, and by that left side circulated through the body.

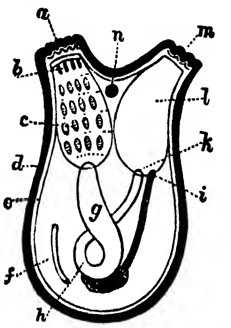

Fig. 2.--Diagram of Sea-squirt Structure.

a, Mouth; *b*, Tentacles; *c*, Breathing Sac; *d*, Test; *e*, Mantle; *f*, Heart; *g h*, Digestive System; *i*, Oviduct; *k*, Anus; *l*, Atrial Sac; *m*, Atrial Aperture; *n*, Nerve Mass.

In a frame of the complexity of organisation of bird or mammal, such an arrangement is found in perfection. The heart, with its cavities and valves, is a complex piece of natural machinery destined to perform a complex function. In the sea-squirts, however, we stand on a different platform. There, we have to face apparently the same functions, but we do not expect the complexity of apparatus wherewith to discharge them. True, in some animals (*e.g.* fishes) the difficulty is surmounted by causing the heart to perform one half the duty it discharges in man. In the fish the heart performs one function only—that of sending impure blood to the gills for purification. But, in the sea-squirt economy, a means for converting a simple heart into a complex worker has been attained in a fashion unparalleled in the animal world. The sea-squirt's heart (Fig. 2, *f*) is a mere contractile tube, which opens, at either end, into blood-vessels. Of these vessels, one set passes to the branchial sac, to carry thereto blood requiring aëration. From the other end of the heart originate vessels which pass to the organs of the body, conveying to the system the renewed and purified fluid. Nature's problem is, therefore, simply that of causing this plain contracting tube to discharge the double duty of propelling blood to the branchial sac, and of also sending it out through the body. With the double heart of man, this end is attained readily and satisfactorily. Simultaneously, our lungs and bodies receive blood. But with the simple heart of the sea-squirt such an arrangement is impossible, inasmuch as there is but one main blood-current and one propelling organ, forming, moreover, part of the tract through which the blood has to pass. To propel blood either way at once would be an easy task; but to send blood alternately to the sea-squirt's body and to its breathing system, without mingling the two streams, might seem a feat impossible of solution, according to the ordinary rules of animal mechanics, even by Nature herself. Let us see how the difficulty has been overcome.

When the heart of a living sea-squirt is carefully observed, a regular and periodical reversion of its action is noticed. Thus for so many beats it will propel the blood towards the breathing sac; performing thus the function of the right side of man's heart, and sending impure blood to be purified in the branchial chamber by means of the oxygen of the sea-water admitted thereto. Then the heart ceases its action for a moment, and when it begins to contract anew, the direction of its motion is seen to be in the opposite direction, namely from the branchial sac and towards the body. By this latter action the purified blood is distributed through the system; such a function being analogous to that performed by the left side of man's heart. The rate of pulsation of the sea-squirt's heart varies; the heart contracting from 48 to 75 times per minute; whilst it may make from 45 to 180 beats in one direction, and, after a pause of some two beats or so, make 170 or so contractions in the other direction. Now such a peculiar and periodical alteration of the heart's action is altogether anomalous. We know of no parallel instance to this in the whole animal world, if we except the case of a low worm (*Phoronis*), in which there is a reversion of the blood-current, hardly so well marked, however, as in the sea-squirt. By a peculiar alteration and modification of its action, therefore, Nature has enabled the sea-squirt's heart to perform the double function which, as we have seen, the heart of the highest animals alone discharges. Even the fish, which has a heart anatomically more complex than that of the sea-squirt, possesses a circulating organ at the same time physiologically (that is, as to its function and work) less perfect than that of our sea-squirt. For in the fish, as above remarked, the heart simply sends the impure blood to the gills for purification, and takes no direct share in distributing the pure fluid through the system.

The history of the sea-squirts may appropriately be closed with the brief chronicle of their development. It was the great Harvey who first enunciated the doctrine which modern physiology substantiates as indisputable, namely, that every living being springs from an egg. The sea-squirt is no exception to this rule. The bag-like organism attached to the oyster-shell was once an egg; it appears before us as the results of the development of a single egg; and in truth, of all other sea-squirts, whether simple or compound, the same remark holds good. For these animals number both simple and compound forms in their ranks. One classification of them divides them into (1) the solitary or simple sea-squirts (Fig. 1, A), (2) the social ones (Fig. 1, C), and (3) the compound forms (Fig. 1, D). The "social" forms (such as Clavellina) remind one somewhat of strawberries in their manner of growth. Just as these plants are connected to one another by a creeping stem or "runner," so the "social" sea-squirts are united by a *stolon* or creeping root, which joins the individuals of the group together. From the "social" to the "compound" sea-squirts is a step involving but a difference in degree. There is simply closer union between the "compound" form than between the "social" ones. The *Botryllus* found adhering to tangle, &c., for instance, exemplifies the compound sea-squirts. Here we see a star-shaped being with a central atrial aperture, common to the members of the colony, each representing a ray of the star, and each possessing its own mouth-opening, and its own body. Botryllus is, in reality, a sea-squirt colony (Fig. 1, D).

But simple or compound, all sea-squirts arise, directly or indirectly, from an egg (Fig. 3). What that egg becomes depends, of course, upon the character of the parent—for, as in higher life, so in normal sea-squirt existence, "like begets like." The first stages (Fig. 3, A, B, C,) in the development of the sea-squirt's egg are just those that are witnessed in the development of the eggs of all animals. The egg substance divides and sub-divides so as to form a mass of cells, from which the young animal's frame is to be built up. The succeeding changes, as every zoologist knows, are marvellously like those witnessed in the development of Vertebrate animals, and particularly in that of the lowest fish—the Lancelet. For the young sea-squirt soon acquires a tail (Fig. 3, F), and appears as a little free-swimming tadpole-like body, utterly unlike its freed parent and progenitor. It possesses sucker-like processes for attaching itself to fixed objects; but the most remarkable features of the young sea-squirt are seen in the facts, firstly, that it develops in its back region a cellular rod exactly corresponding to that rod (the *notochord*) which in Vertebrates is replaced by the spine; and secondly, that its nervous system is developed apart from the other systems of the body as in vertebrate animals. It is this extraordinary likeness to the latter which has given to the sea-squirts a high importance in the eyes of modern naturalists.

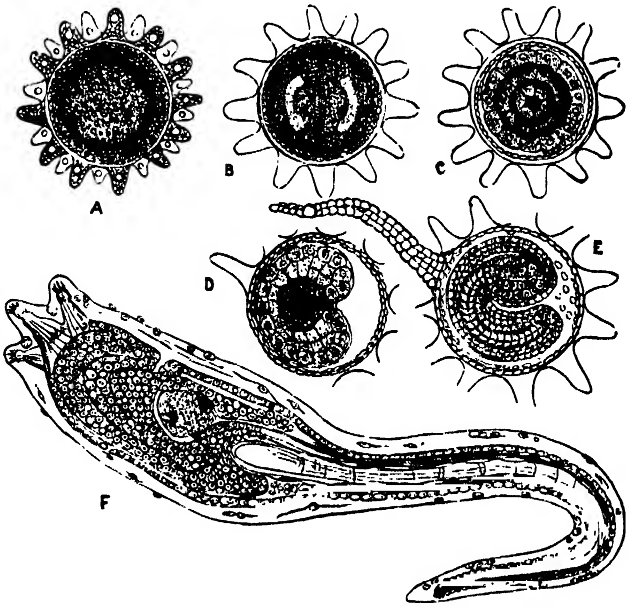

Fig. 3.—Development (A—F) of Sea-squirt. (*After Haeckel.*)
At F is seen the tailed larva, with notochord and internal organs already well developed.

Sooner or later, however, the body of the tadpole-like sea-squirt becomes moulded into the form of the adult. The tail disappears in due course; the young organism attaches itself to its oyster-shell, and the bag-like form with its double openings is soon developed by way of completing the life-history of the animal. It is noteworthy that there are several forms of sea-squirts known in which the tail of early life remains as a permanent possession of the animal. One of these forms, *Appendicularia*, is well-known; it uses its tail as a swimming organ, and there are other sea-squirts (such as *Doliolum*, a barrel-shaped form) which swim freely upon the surface of the sea, like Appendicularia. Two of the best known of the free-swimming forms are *Salpa* and *Pyrosoma.* Salpa exists under two guises—one is the single *Salpa*, and the other a long chain of individual Salpæ joined together (Fig. 4, A, B). The curious point about the Salpa consists in the fact that the single Salpas invariably produce "chain" Salpas as their offspring, whilst the "chain" Salpas as invariably give origin to single forms. As Chamisso observed, this process seems as if a Salpa never resembled its parent, but its grand-parent. Probably, however, there is but *one* true form—namely, the "chain" Salpa—included in the process; the single Salpas being merely detached buds of the chain stock. *Pyrosoma* deserves mention, lastly, not merely because it is a colony of compound sea-squirts and swims freely on the surface of the sea (Fig. 5), but because at night it shines with a vivid phosphorescent light. As in other animals, so much nerve or vital "force" is converted into light, through the action of a "light organ" placed near the mouth-apertures of the individuals. The light of pyrosoma, like the phosphorescence of other sea animals, may recall to mind the "Ancient Mariner's" vivid description of this phenomenon; although the "water-snakes" of Coleridge have become transformed by the more sober fact of science into the luminous and less ambitious "sea-squirts."

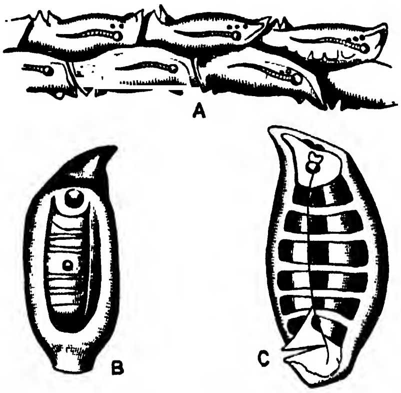

Fig. 4.—Salpa zonaria. A, Chain; B, C, Simple Form.

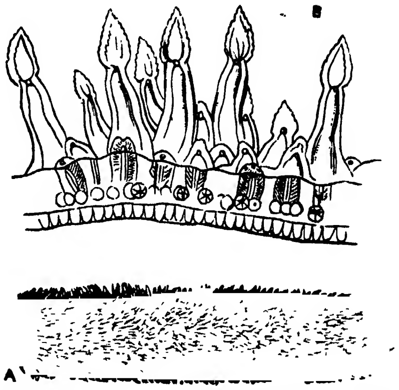

Fig. 5. - A, Pyrosoma; B, Portion, Magnified.

EARTHQUAKES.

By Professor P. Martin Duncan, F.R.S., etc.

FORTUNATELY, in the United Kingdom only very slight shocks of earthquake are felt on very rare occasions, and usually these are restricted to certain parts of the mountainous districts of Scotland, the north-west[*] of England, and Wales. But it has happened that a very decided shake has been felt from Kent into the Midland Counties, doing, however, little or no mischief. Slight as may be the shake, if one is felt it is never forgotten, for the body is very slightly lifted up, or moved forwards, and returned to its original position, and the mind is impressed with the energy existing within the earth which performed the unusual operation.

In other countries, and especially in those in, near, or between volcanic districts, the earthquake has always been a terrible natural phenomenon (Fig. 1). Causing much loss of life, great fear, and loss of property, they were, and in some countries still are considered especial evidences of divine vengeance Producing marked results in the face of nature, and having been felt during every age of the earth, and even where there are no men, the scientific consider them as inevitable occurrences, produced according to natural law in the divine scheme of nature. The subject of earthquakes can only be considered reasonably, by accumulating accurate histories of them and of their results, and then, by applying reasoning to the phenomena, to attempt an explanation of them. Hence its division into a descriptive part, which is now under consideration, and into a theoretical study termed seismology, the main facts and doctrines of which will be explained in a future page.

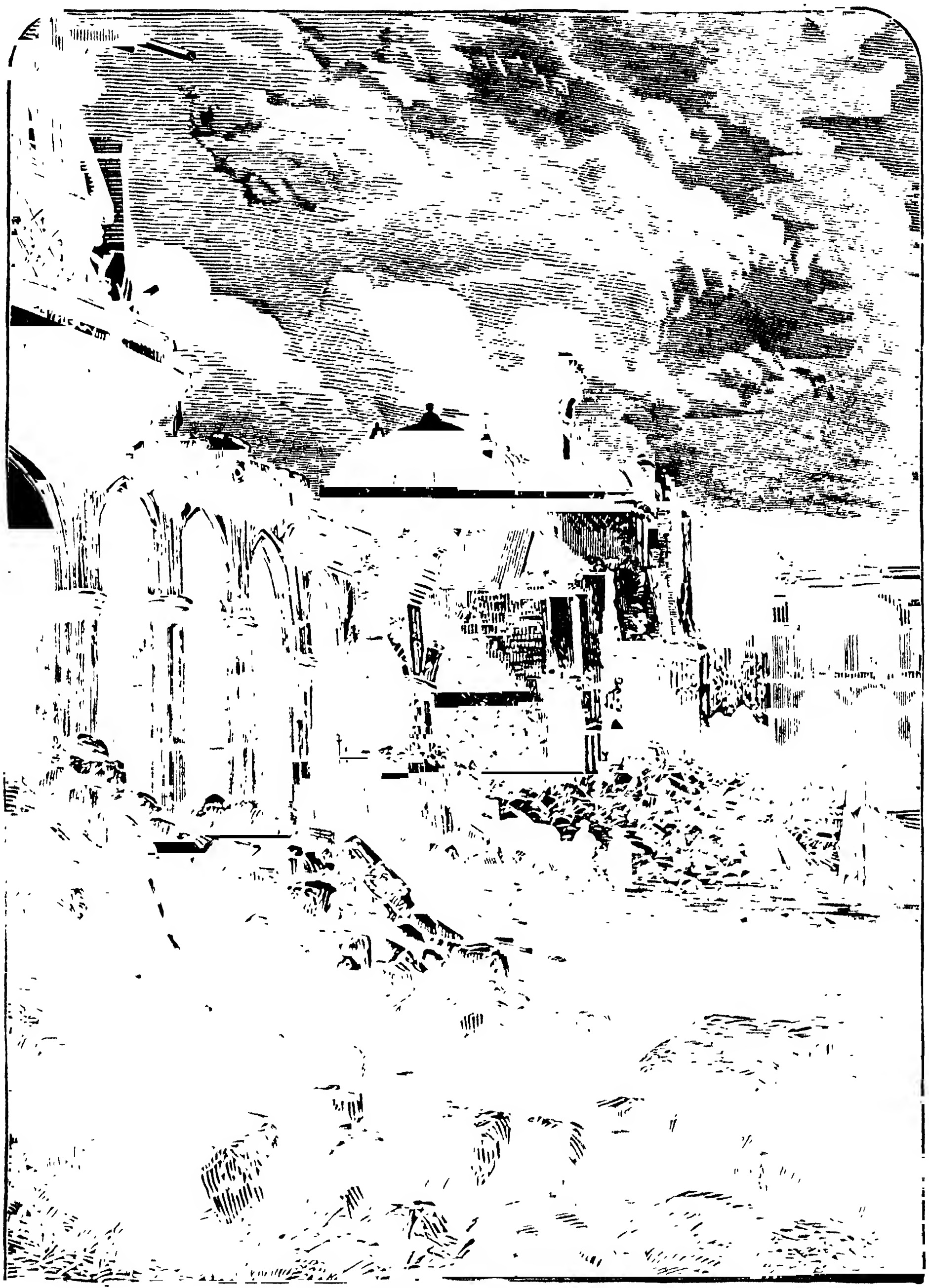

Fig. 1.—THE JESUITS' CHURCH, AREQUIPA, PERU. (*After the Earthquake of August, 1868.*)

One of the most awful earthquakes of modern times occurred without any premonitory indications, and it was most intense in a district which had hitherto been nearly free from them. On Nov. 1, 1755, the town of Lisbon presented its usual appearance, and the ordinary routine of life and business was being carried on, when suddenly, and without the least warning, a violent shock of earthquake threw down the greater part of the place. Houses fell in, streets were filled with the wreckage, and it is believed that 60,000 people lost their lives in the course of a few minutes. It is said that just before the shock a noise as of thunder was heard underground, and this is quite possible. Not only were the mountains in the neighbourhood of the city shaken, but some were split, and huge masses of their rocks were thrown down into the valleys close by; but the sea floor also suffered, for the sea retired, and the bar of the Tagus was left high and dry, and then in a few seconds a vast wave rolled in, rising to fifty feet, at least, above ordinary water level. The alarm caused by the falling buildings impressed the frightened crowd of people that the beautiful marble quay on the river-side was a safe place, as it was beyond the reach of falling ruins. A great concourse of people assembled there, but suddenly the structure sank down bodily with all on it, and no vestige ever appeared. A number of boats and small vessels, which were anchored near the quay, and many of which had people in them, were carried down in the whirlpool produced by the subsidence. The quay is said to have sunk, according to the level on which the new quay was erected, at least thirty feet. The amount of the surface of the earth which was affected by this earthquake was at least four times that of Europe. The shock was felt in the Alps, Pyrenees, and on the coast of Sweden, in the small inland lakes on the shores of the Baltic, in Central Germany and Northern Germany, and in the British Isles. The hot springs of Töplitz became dry and again began to flow, but in vast quantity, and the water was discoloured by ochre. Alterations in the springs of the Pyrenees also occurred.

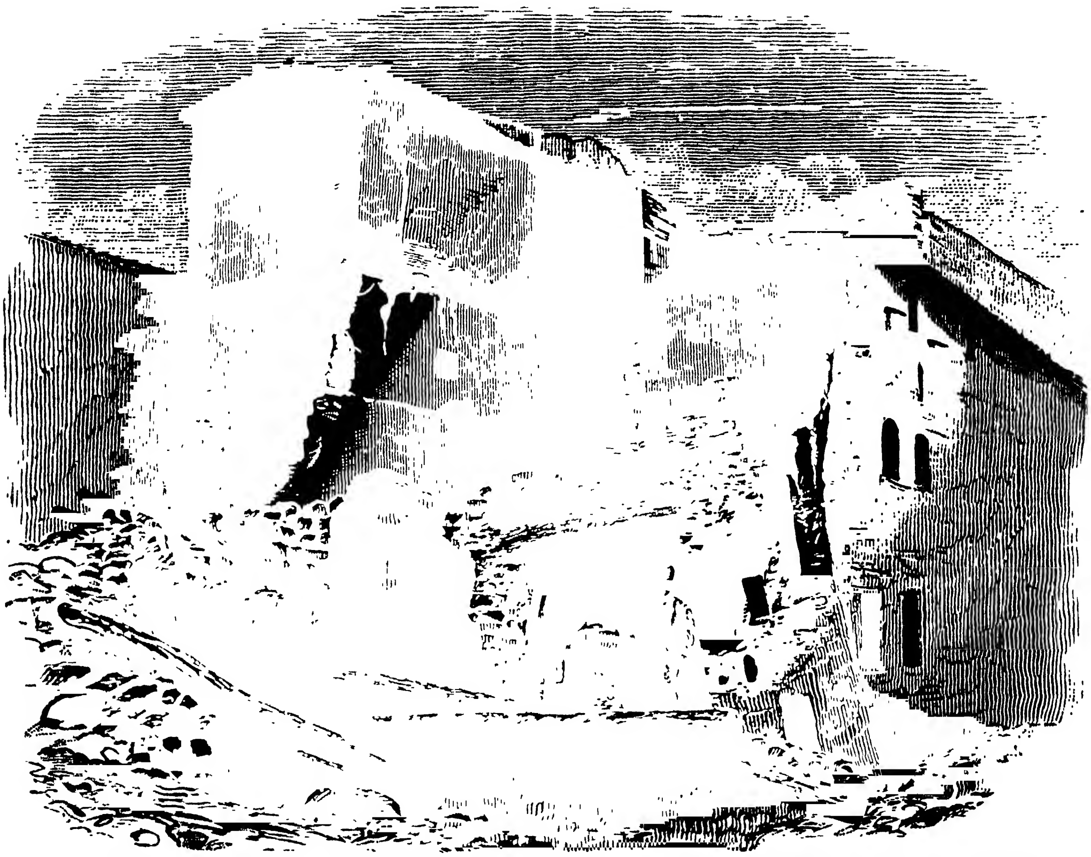

Fig. 2.—Street in Polla. (*After an Engraving in "The Great Neapolitan Earthquake of* 1857," *by Robert Mallet.*)

In the far-off West Indian Islands of Antigua, Barbadoes, and Martinique the usually small tide rose above twenty feet, and the water was discoloured and inky in blackness. The movement was sensible in the great lakes of Canada. At Algiers and Fez, in North Africa, the agitation of the earth was as violent as in the Spanish Peninsula; and many people lost their lives in Morocco, it is said, by the earth opening and swallowing them up. The shock was felt at sea, and captains of ships, off the coast, thought that they had touched ground. One Captain Clark, when off Denia, on the east coast of Spain, between nine and ten in the morning, had his ship shaken and strained as if she had struck upon a rock, so that the seams of the deck opened, and the compass was overturned in the binnacle. Another ship forty leagues west of St.

Vincent experienced so violent a concussion that the men were thrown up from the deck. The agitation of many of the lakes, rivers, and springs in England and Scotland was remarkable. At Loch Lomond, in Scotland, the water, without the least apparent cause, rose against its banks and then subsided below its usual level. The greatest height it reached was two feet four inches. A great wave swept over the coast of Spain, and it is said to have been sixty feet high at Cadiz. On the African coast the wave rose and fell eighteen times, and at Funchal on the distant island of Madeira the water rose full fifteen feet above high-water mark, although the tide, which ebbs and flows there about seven feet, was then at half-ebb. Besides entering the city and committing great havoc, it overflowed other seaports in the island. Kinsale, in Ireland, had an irruption of water into the harbour which whirled the fishing boats about and poured into the market-place.

The earthquake shock was felt at Madeira twenty-five minutes after it destroyed Lisbon, and the great sea wave appears to have travelled from the coast of Portugal to that island in two and a half hours.

About four years after this sudden and solitary earthquake shock, a series occurred in Syria; that is to say, during three months shock after shock occurred over a space of some 10,000 square leagues. Damascus, Sidon, Tripoli, and many other towns were wrecked, and great numbers of people perished, and it is said that 20,000 were killed in one valley alone.

Chili, on the western coast of South America, has been celebrated for its severe earthquakes, and for their remarkable results on the physical geography of the district. On November 19, 1822, a shock was felt there and elsewhere throughout a space of 1,200 miles from north to south; and when the country round Valparaiso was examined subsequently, it was found to have been permanently upheaved between three and four feet. The whole coast appears to have been irregularly lifted up beyond its ordinary level above the sea. The shocks continued at intervals—forty-eight hours rarely passing without one—up to the end of September, 1823, and the total upheaval of the coast was from two to four feet, and inland to five, six, or seven feet—this change of level taking place over 100,000 square miles, an extent of country equal to five-sixths of the surface of England, Scotland, and Ireland. Another severe earthquake happened in 1835, whilst that accurate observer of nature, Charles Darwin, was in South America. On February 20 he writes, "This day has been memorable in the annals of Valdivia, for the most severe earthquake experienced by the oldest inhabitant. I happened to be on shore, and was lying down in the wood to rest myself; it came on suddenly and lasted two minutes, but the time appeared much longer. The rocking of the ground was very sensible. The undulations appeared to my companion and myself to come from due east, whilst others thought they proceeded from south-west; this shows how difficult it sometimes is to perceive the direction of the vibrations. There was no difficulty in standing upright, but the motion made me almost giddy; it was something like the movement of a vessel in a cross ripple, or still more like that felt by a person skating over thin ice, which bends under the weight of his body. A bad earthquake at once destroys our oldest associations; the earth, the very emblem of solidity, has moved beneath our feet like a thin crust over a fluid; one second of time has created in the mind a strange idea of insecurity, which hours of reflection could not have produced. In the forest I felt only the earth tremble, but saw no other effect. Captain FitzRoy and some officers were at the town during the shock, and there the scene was more striking; for although the houses, being built of wood, did not fall, they were violently shaken, and the boards creaked and rattled together." Soon after he heard the terrible news that not a house in Concepcion or its port was standing, that seventy villages were destroyed, and that a great wave had almost washed away the ruins of Talcahuano. "Of this latter statement I soon saw abundant proofs, the whole coast being strewed over with timber and furniture, as if a thousand ships had been wrecked. During my walk round the island I observed that numerous fragments of rock, which, from the marine productions adhering to them, must recently have been lying in deep water, had been cast up high on the beach. The island itself as plainly showed the overwhelming power of the earthquake as the beach did that of the consequent great wave. The ground in many parts was fissured in north and south lines, perhaps caused by the yielding of the parallel and steep sides of this narrow island. Some of the fissures near the cliffs were a yard wide. Many enormous masses had fallen on the beach; and the inhabitants thought that when the rains began greater slips would occur. The effect of the vibration on the hard primary slate which composes the foundation of the island was still more curious; the superficial parts of some narrow ridges were as completely shivered as if they had been blasted by gunpowder."

Mr. Darwin states that this convulsion has been more effectual in lessening the size of the island of Quiriquina than the ordinary wear and tear of the sea and weather during the course of a whole century. He landed on the next day, and visited Talcahuano, and afterwards Concepcion, and was impressed with the awful yet interesting spectacle he beheld. He writes: "The earthquake commenced at half-past eleven in the forenoon. In Concepcion each house or row of houses stood by itself, a heap or line of ruins; but in Talcahuano, owing to the great wave, little more than one layer of bricks, tiles and timber, with here and there a part of a wall left standing, could be distinguished. The first shock was very sudden. The Major-domo of Quiriquina told me that the first notice he received of it was finding both the horse he rode and himself rolling on the ground, and on rising up he was again thrown down. Innumerable small tremblings followed the great earthquake, and within twelve days no less than 300 were counted. In the town of Concepcion, which was built with all the streets running at right angles to each other, the ruin was caused by a shock or vibration coming from the south-west. This upset all the houses placed north-west and south-east, and fissures opened in the ground along the direction of the houses. Some buildings, such as the Cathedral, stood in part, and were often found twisted; but the rest were thrown down and the stones rolled away."

Three hundred and sixty miles to the north-east the island of Juan Fernandez was violently shaken, so that the trees beat against each other, and a volcano burst forth into activity close to the shore. Moreover, Chiloe, about 340 miles southward of Concepcion, was shaken, and two existing volcanoes in the Andes close by, burst forth. Vast, indeed, was the land surface shaken, and a corresponding earthquake seems to have occurred beneath the sea. The wave already alluded to was its result. For shortly after the shock at Concepcion, a great wave was seen from the distance of three or four miles approaching with a smooth outline in the middle of the bay; along shore it tore up trees and houses as it swept onwards with irresistible force. At the head of the bay it broke into a perfect line of white foaming breakers, which rushed up to a height of twenty-three feet above the highest spring tides. Their force moved a gun with its carriage, weighing four tons, more than fifteen feet. In one part of the bay a ship was pitched high and dry on shore, and was carried off, again driven on, and again carried off. The great wave travelled slowly. Terrible as was the loss of life, and vast as was the loss of property, the permanent effects of this earthquake on the surface of the earth were indeed remarkable. The land round the bay was upraised two or three feet, and about thirty miles off the elevation was greater, and the inhabitants got shell-fish off the rocks which they had to dive for previously. Finally, the space of the earth along which volcanic matter was cast forth that day was 720 miles in one line and 400 in another line, at right angles to the first. This catastrophe was a grand repetition of one which occurred in the same locality eighty-four years before (1751). The ancient town of Penco was then totally destroyed by an earthquake, and the sea rolled in over it. The ancient port was rendered useless, and the inhabitants built another town about ten miles from the sea-coast, in order to be beyond the reach of similar inundations. This was Concepcion. The west coast of South America appears, indeed, to be the land of earthquakes and of the accompanying sea wave. Thus Lyell records that in 1746 Peru was visited, on October 28th, by a tremendous earthquake. In the first twenty-four hours 200 shocks were experienced. The ocean twice retired and returned impetuously upon the land; Lima was destroyed, and part of the coast near Callao was converted into a bay. There were twenty-three ships, great and small, in the harbour of Callao, of which nineteen were sunk, and the other four, among which was a frigate called *San Firmin*, were carried by the force of the waves to a great distance up the country, and left on dry ground at a considerable height above the sea. The number of inhabitants in this city amounted to 4,000, and only 200 escaped, twenty-two of whom were saved on a small fragment of the fort of Vera Cruz, which remained as the only memorial of the town. Other portions of its site were completely covered with heaps of sand and gravel.

Earthquakes are common on the other side of this region, and occasionally affect the West Indian Islands severely. An old yet well-recorded instance is that of the earthquake of Jamaica, in 1692. The ground swelled and heaved like a rolling sea, and was traversed by numerous cracks, 200 or 300 of which were seen at a time, opening and then closing rapidly again. Many people were swallowed up in these rents; some the earth caught by the middle and squeezed to death; the heads only of others appeared above ground; and some were engulfed and then cast forth again with great quantities of water. Such was the devastation that even in Port Royal, then the capital, where more houses are said to have been left standing than in the whole island besides, three-quarters of the buildings, together with the ground they stood on, sank down, with their inhabitants, entirely under water. The large stone houses on the harbour side subsided so as to be from twenty-four to forty-eight feet under water; yet many of them appear to have remained standing, for it is stated that after the earthquake the mast-heads of several ships wrecked in the harbour, together with the chimney-tops of houses, were seen just projecting above the waves. A tract of land round the town, about 1,000 acres in extent, sank down in less than one minute during the first shock, and the sea immediately rushed in. The *Swan* frigate, which was repairing in the wharf, was driven over the tops of many buildings and thrown upon one of the roofs, through which it broke. The breadth of one of the streets is said to have been doubled by the earthquake. Lyell states that he was informed by the late Admiral Sir C. Hamilton that he frequently saw the submerged houses of Port Royal in the year 1780, in that part of the harbour which lies between the town and the usual anchorage for men-of-war; and that Lieutenant Jeffery, R.N., saw the remains of houses in four or eight fathoms in clear water. Out of the town the ruin was vast. Some plantations sank, and were covered in after years by a lake of fresh water; several tenements were buried in landslips; and one plantation was removed half a mile, by a slide, from its place—growing crops and all. Between Spanish Town and "Sixteen-Mile Walk" the high and perpendicular cliffs bounding the river fell in, stopped the passage of the river, and flooded the latter place. The Blue Mountains were much shattered, fissured, and their soil set loose in landslips.

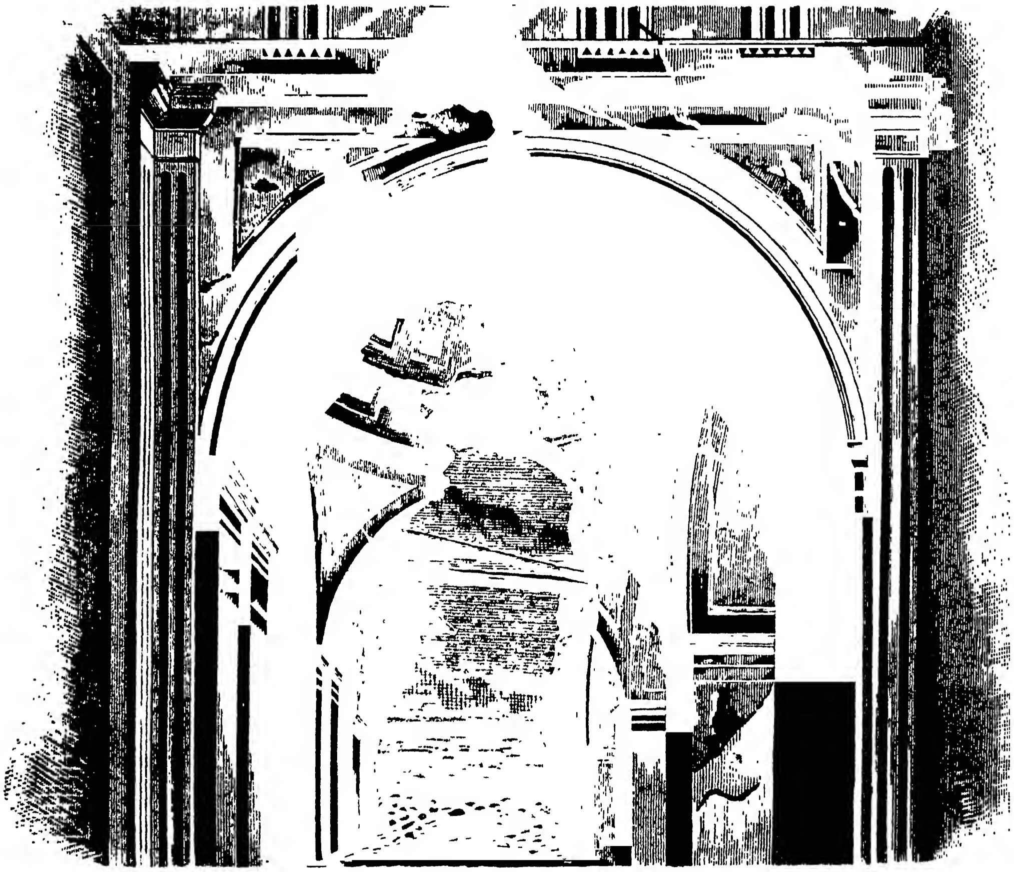

Fig. 3.—Cathedral of Tito, as Shattered by the Earthquake of 1857. (*After Robert Mallet.*)

A friend of the writer of this notice was residing on a small island near the principal town of Martinique, in a house built mainly of wood. Early one morning, whilst dressing, he felt a slight shock of an earthquake, and, taking up his watch, he and the rest of the family ran out into the grounds. Immediately afterwards a second shock was felt, and he looked at his watch, and on raising his eyes saw the building collapsing as if it had been made of cards, and also a great dust over the town in the distance. In three seconds all was quiet underground, but parts of the house kept falling. An hour or two afterwards, when the dust and smoke were carried off by the wind, the town on the island opposite was seen to be a mere wreck. On landing there as soon as was possible, and on inquiring of the people the nature of the shock, it was generally stated that it lasted at least twenty minutes—so great, under the influence of terror and danger, was the discrepancy.

The late Mr. David Forbes was residing at Mendoza, a town on the flanks of the Andes, close to the great plains running for many miles to the east—a quiet, lazy town where life passed easily and where men's wants were not very great, was this very enjoyable city. Forbes rode out one day with some friends, and when some miles from the town they saw a long line of dust, and then a rolling motion of the ground threw them down, horses and all. They had been accustomed to earthquakes in other parts of the district, and knew that something terrible must have happened at Mendoza. Galloping there, they found the city destroyed, some thousands of its inhabitants killed, and for days they worked at extricating the wounded. The city on the hill-side had felt the shock from the plain, and this moved, but the mountain stood still or suffered comparatively little movement; the push of earth against the unyielding hills threw down nearly every house.

The years 1811 and 1812 were terrible for their earthquakes, and in the first of them the ground of South Carolina and the Valley of the Mississippi, from New Madrid to the mouth of the Ohio in one direction, and to the St. Francis in another, was convulsed in such a degree as to produce new lakes and islands. Old lakes were drained, water was forced out of the ground, and the trees were bent down and got their branches interlocked with others as they were restored to their position. Lyell visited the scene years afterwards, and noticed the lakes, the rents in the soil, and the great fissures, and was struck with the grand vegetation of cotton trees on the district once occupied by a piece of water. These results were the product of a succession of shocks, which occurred during several successive months, and they seem to have stopped in 1812, after a most destructive earthquake took place far south, at Caraccas. The whole of that city and its splendid churches were in an instant a ruin, and 10,000 people perished. A few days afterwards great rocks were detached from a neighbouring mountain, and Humboldt states that the hills, consisting of hard, solid rocks, shook more than the plains. Subsequently a volcano burst forth far away in St. Vincent.

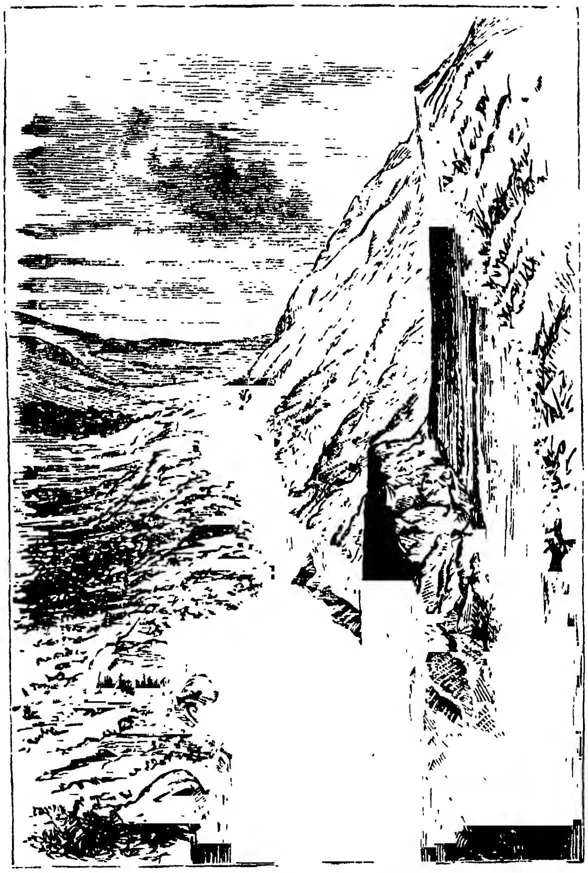

Fig. 4.—View near the North End of the Gorge, Bella. (*After Robert Mallet.*)

Even so late as 1879, earthquakes of great violence shook the highly volcanic district of San Salvador. More than 600 shocks were felt during the last ten days of the year, and were heaviest near the lake Ilopany. On the last day of the year a shock came that broke the telegraph wires, and made the ground on which the observer stood a perfect network of cracks. It opened great springs, increased the water supply of the rivulets to ten times its former amount, and muddied the waters of the lake. In many places thousands of tons weight of earth were rolled down the hills or slipped into valleys. The end of all this disturbance was the sudden appearance of a volcanic cone in the lake.

That part of Southern Italy which is called Calabria Ultra, and also part of Sicily, a district situated between the volcanoes of Vesuvius near Naples and Etna in Sicily respectively, suffered from a great earthquake in 1783, and a second in 1857 (Figs. 2—4). A careful examination of the last terrible visitation enabled Mr. R. Mallet to form a theory and explanation of the shock, to which allusion will be made in a future page when discussing "Seismology," or the nature of earthquakes. It, moreover, together with the examination of the history of the former catastrophe, enabled the results of the earthquakes to be noticed, and their peculiarities employed in reasoning upon some of the great geological changes which have occurred in the earth. The greater part of the towns of Calabria were built on isolated hills for the sake of security and defence, during the Middle Ages. The sides of the hills were often precipitous on three of the sides. The district began to suffer shocks in the February of 1783, and Pignatoro, a physician who resided at Monteleone, a town placed in the very heart of the disturbed locality, kept a register of the tremblings, distinguishing them into four classes, according to their degree of violence. There were 949 in that year, of which 501 were great, and in the following year there were 151, of which 98 were of the first magnitude. They lasted until the end of 1786.

The greatest amount of damage was done at Oppido, and in a radius of twenty-two miles around that town. The first shock, on February 5, 1783, threw down in two minutes the greater part of the houses in all the cities, towns, and villages from the western flanks of the Apennines in Calabria Ultra, between the thirty-eighth and thirty-ninth parallel of latitude, to Messina, in Sicily, and convulsed the whole surface of the country. The shock was felt with less severity over the greater part of Sicily, and as far north as Naples. Thus the extent of the catastrophe was not nearly as great as that of many of the South American earthquakes, but it happened in a highly civilised country, and at a time when men like Sir William Hamilton and Dolomieu were at hand to investigate the results, and during that ferment of scientific thought which distinguished the last years of the last century. Hearsay and traditions were therefore not included in the history of the earthquake, but careful and trained observers noted and delineated the phenomena. The loss of life was not less than that of 40,000 individuals, and at least 20,000 died subsequently from the results of injuries, fright, and exposure. By far the greater number were buried under the ruins of their houses, and many were burnt in the conflagrations which followed on the falling in and destruction of the buildings. Dolomieu, who visited Messina after the shock, describes the city as still presenting, at least at a distance, an imperfect image of its ancient splendour. Every house was injured, but the walls were standing; the whole population had taken refuge in wooden huts in the neighbourhood, and all was silence in the streets; it seemed as if the city had been desolated by the plague. But he writes, "When I passed over to Calabria, and first beheld Polistena, the scene of horror almost deprived me of my faculties—my mind was filled with mingled compassion and terror. Nothing had escaped—all was levelled with the dust; not a single house or piece of wall remained; and on all sides were heaps of stone, so destitute of form that they gave no conception of there ever having been a town on the spot."

One of the most gigantic results of this earthquake was the disconnection of the strata consisting of softer substances from the granite and hard rock, which they flanked, along the Apennines. Thus the earth on the granite of the mountains Caulone, Esope, Sagra, and Aspromonte slid over the solid and steeply inclined hard rock and descended bodily into the plains lower down, leaving almost uninterruptedly from St. George to beyond St. Christina, a distance of from nine to ten miles, a chasm between the soft and hard rock. The formation of longitudinal valleys in relation to mountain chains may therefore be the result of earthquake in the first instance. A whirling movement was exerted in some places, and the upper stones of obelisks and pillars were displaced, the lower retaining their usual position, and the displacement was that of turning round more or less. Masses of earth were cast upwards, and the pavement stones of some towns were found lying with their lowest sides upwards, whilst there were well-authenticated instances of the upward casting to the height of some feet of loosely lying structures. The rending and fissuring of the ground at Messina were remarkable, and the formerly level shore was slanted or inclined towards the sea, and the water was found to be deeper; moreover, the quay sank down fourteen inches below sea level, and the houses close by were much fissured. In the territory of Soriano faulting of strata occurred, and one part became some ten feet lower than the rest (Fig. 4). On the other hand, in the town of Terranuova some houses were seen uplifted above the common level. Men and cattle were engulfed in the fissures which opened as the shock proceeded, and at Ferocarne the fissuring could be compared to the cracks in a starred and half broken pane of glass in their number and direction. Deep abysses occurred, and at Cannamaria four farmhouses, several oil stores, and some dwellings were so completely lost in a chasm that no vestiges have ever appeared. Some of these cracks and rendings led to subterranean cavities which had existed before. Some plains were covered with circular hollows, about the size of carriage wheels; usually these were funnel-shaped, and the tube part went into the earth for a greater or less distance. Landslips crossed many a river and blocked it up, causing lakes to form, and the government reporters gave 218 lakes as having this origin. Along the coasts of the Straits of Messina, near the celebrated rock of Scylla, the fall of huge masses from the cliffs overwhelmed villas and gardens, and the Mount Jaci was so shaken that a great mass of it rolled down. Immediately afterwards the sea, rising more than twenty feet above the level of the district, swept away men, cattle, and boats, destroying the Prince of Scylla and 1,430 of his people. A violent earthquake occurred in Cutch, in the delta of the Indus, on January 16, 1819, and the movement was felt over a radius of 1,000 miles to the north-east, east, and south-east. Deepening of the estuary and sinking of the fort and village of Sindree, and the inrush of the sea covering 2,000 square miles, were the principal results; but an extent of country fifty miles long and sixteen broad was permanently elevated ten feet. The repetition of shocks, of greater or less severity, week after week, is often recorded, and also their extension over great spaces; their relation to other and distant earthquakes and to the outburst of volcanoes must have been noticed also. This has been particularly the case in more recent earthquakes. Thus, a terrible earthquake in the island of Ischia on March 6, 1881, destroying the town of Casamicciola, was succeeded next month by another equally destructive in Chios; and on July 29, 1883, a second and still more terrible earthquake in Ischia reduced Casamicciola to ruins, and destroyed 4,000 lives. Again, on August 21, 1886, a perceptible earthquake shock was felt at Kilsyth, near Glasgow. This was followed on August 27 by a most terrible earthquake, causing wide devastation and the loss of many lives over the whole of the Ionian Islands and Western Greece; and on August 31 these were followed again by a series of most violent shocks, lasting for weeks, in the Southern States of North America, which transformed Charleston and many other towns to heaps of ruins. Earthquakes often precede a volcanic eruption, and these last have been called safety-valves, but really they are both part of a grand phenomenon. This was well exhibited in the terrible volcanic eruption at Rotomahana in New Zealand on June 11, 1886, which was preceded by a series of almost constant sharp earthquake shocks for about eight hours.

The upheaval and subsidence of land, the slipping of land, and the fall of rocks, are most important in their relation to permanent changes in the aspect of nature. The great waves of the sea produce more in the way of change in a few minutes than can be performed during centuries of ordinary wear and tear. Often distant countries like New Zealand learn of South American earthquakes by the sudden arrival of waves which have crossed the thousands of miles of the Pacific hour after hour in their destructive voyage.

SATURN.

By W. F. Denning, F.R.A.S.

FROM whatever view the planet Saturn is considered, it must be granted that he forms, with his rings and satellites, a most remarkable and magnificent object. Scarcely inferior to Jupiter in magnitude, and vastly exceeding the combined bulk of Mercury, Venus, the Earth, and Mars, he merits attention on account of his great dimensions, apart from the fact that he is surrounded by no less than eight satellites, and that his equator is girded by a series of luminous rings, offering phenomena unique in the solar system (Fig. 1). He cannot be regarded as a very conspicuous object in the firmament, for his brilliancy always falls much below the lustre of Venus, Jupiter, or Mars. At the best he shines with a dull, ruddy light, scarcely brighter than a first-magnitude star, and there is nothing about the ordinary aspect of the planet to indicate the splendour and extent of detail which is revealed in a powerful telescope. Situated far outside the orbit of Jupiter, at a vast distance from the sun, we cannot wonder that to the unaided eye his visible appearance is by no means exceptional. His huge proportions are apparently moderated by great distance, while his ringed sphere and numerous retinue of moons are hopelessly beyond the reach of mortal ken, so that before the invention of the telescope their existence was utterly unknown. It is only by the application of efficient instruments that his wonderful system becomes displayed to our view, and we can readily understand the difficulty of their early discovery by the imperfect and unwieldy glasses used by the old astronomers.

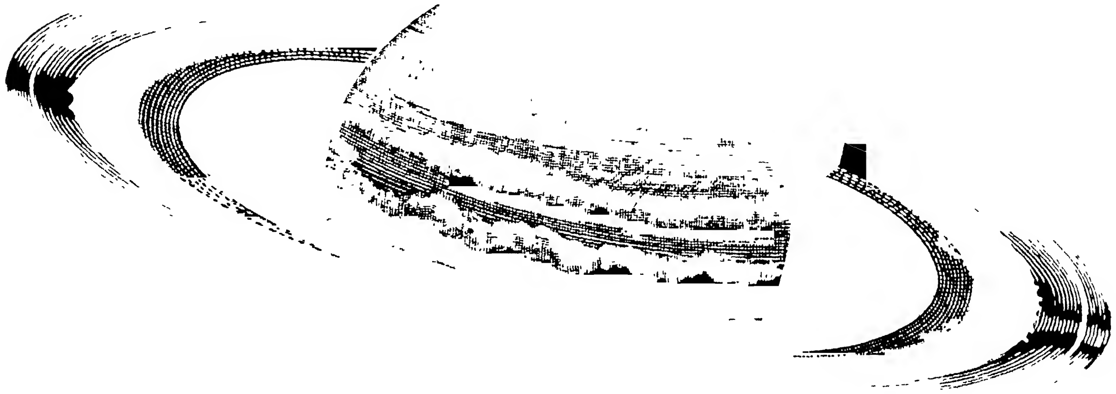

Fig. 1.—Saturn and his Rings.

Saturn is situated at a mean distance of about 372,000,000 miles from the sun, and completes a revolution in slightly less than twenty-nine and a half years. His *real* equatorial diameter has been computed at nearly 72,000 miles; his *apparent* diameter at mean distance is seventeen seconds of arc. The polar compression, though more considerable than that of any other planet, is less noticeable than that of Jupiter, on account of the ring, which modifies the effect. It amounts approximately to one-tenth of the planet's greater axis.

The rings of Saturn are said to have been first distinctly seen by Huyghens, in 1659, or about half a century subsequently to the invention of telescopes. Galileo had some years previously been engaged in observing Saturn, but his instruments seem to have failed in exhibiting the planet in its true aspect. He saw it under an oval form, and interpreted the picture as that of a large planet with a smaller one on each side. His telescope, while thus obviously allowing a glimpse of the ring, was of inadequate power to display its real nature, and Galileo announced to his eminent contemporary, Kepler, that he had "observed the most distant planet to be threefold." But the discovery puzzled its author exceedingly, for, making additional observations, he found that the two smaller bodies perceptibly decreased in size, until finally he could not distinguish them at all! He was confounded at this, and began almost to doubt the evidence of his glasses ; yet he had seen, over and over again, and with the most careful adjustment and focussing of the lenses, the same appearances hanging on the planet's side. He quite failed to account for so startling a phenomenon, and in a letter written in 1612 he thus expressed himself :—"What is to be said concerning so strange a metamorphosis ? Are the two lesser stars consumed after the manner of the solar spots ? Have they vanished, or suddenly fled ? Has Saturn, perhaps, devoured his own children ? Or were the appearances, indeed, illusion and fraud, with which the glasses have so long deceived me ?" No satisfactory answers were forthcoming, but shortly afterwards the planet again exhibited the strange objects which had so perplexed Galileo. The fact of their existence was thus proved, though the explanation of their real character, and the cause of their occasional disappearance was not known until many years afterwards, when, great improvements having been made in the construction of telescopes, the exploration of the heavens was more successfully attempted. In 1659, Christian Huyghens saw the "slender, flat ring" surrounding the planet, and predicted its apparent disappearance in 1671, which really occurred, for the ring being presented edgeways to the earth, it became invisible. What had been so intricate a problem to Galileo was now explained. A bright ring encompassed Saturn, extending a considerable distance from the body of the planet, and giving the appearance of ansæ, or handles (Fig. 2). This ring, being of extreme thinness, was wholly lost to view when its edge alone became illuminated. This happened at intervals of about fifteen years, when the plane of the ring is directed to the sun at the Saturnian equinoxes (as in 1848, 1862, and 1877).

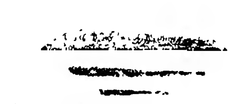

Fig. 2.—Telescopic View of Saturn's Ring, near Disappearance, June 26, 1848. (*Schmidt.*)

Closely preceding and following the disappearance of the ring, it presents the aspect of a broken thread of light extending from the sides of the planet. This has been held to demonstrate great inequalities, in the form of mountainous projections, from the surface of the ring, but it has been more satisfactorily accounted for by supposing it due to the concurrent effect of reflected light from the external and internal edges of the rings. Bond, in 1848, when the rings were near disappearance, made a series of micrometric measures, which fully accorded with this explanation of the beaded form of the ring. The narrow, luminous vein to which it is reduced when lying edgeways to the earth, is far from being equally distinct on both sides. Sometimes only one of the ansæ is visible, and occasionally, when both are evident, a difference in their comparative lengths has been detected.

It was not long after the detection of the ring of Saturn that it was suspected to be double. A dark line, apparently dividing it, was observed by two English observers, named Ball, on October 13th, 1665, who used a "good telescope near thirty-eight feet long, and a double eye-glass." The observation induced the theory that the planet was surrounded by *two* circular rings, and the fact was fully confirmed by Cassini, ten years later, using refracting telescopes of thirty-five and twenty feet focus. The latter instrument had an aperture of nearly two-and-a-half inches, and power of ninety. Cassini recorded his observations in the "Philosophical Transactions" for 1676 as follows :

> "In the bright part of each ansa was a darkish ellipsis, nearer to the outside than to the inside of the ring, as if it was composed of two rings near to one another."

Cassini was evidently unaware that the double ring had been seen ten years before, and the mistake has often arisen of according the honour of its first discovery to Cassini, though Dr. Kitchiner, in his work on "Telescopes" (1825), distinctly quotes the priority of Mr. Wm. and Dr. Ball; and there is little fear that in future years the peculiarity of which they obtained the first view, and gave the first intimation, will be exclusively theirs, seeing that it has received the appellation of "Ball's division in the ring," which at once distinguishes it from the other minor divisions detected in more recent times.

Encke, in 1838, concluded that he saw a division in the outer ring, and in 1843 Lassell and Dawes distinctly observed a dark line on the outer ring, near the extremities of the ellipse, and estimated its breadth as one-third of that of the principal division in the ring. But one of the most astonishing discoveries in connection with the rings was made in 1838 by Dr. Galle, of the Berlin Observatory, who noticed an appearance within the rings, which, though imperfectly reflective, was traceable around the planet. It appeared under the form of a shading, extending from the inner ring towards the globe of the planet, "as if the solid matter of the ring were continued beyond its illuminated surface;" in fact, it gave the impression of an obscure ring situated within the other more highly reflective ones. But though Dr. Galle had thus obtained the earliest view of this remarkable appendage, it remained for others to more thoroughly trace its character. In 1850 and 1851, the attention of astronomers was more fully directed to the subject, and the existence of this dark interior ring was not only finally established, but it was proved to be nearly transparent, for the body of the planet could be distinctly seen through it. This delicate observation requires a good instrument, and acute vision practised in similar work, without which an observer can hardly hope for success.

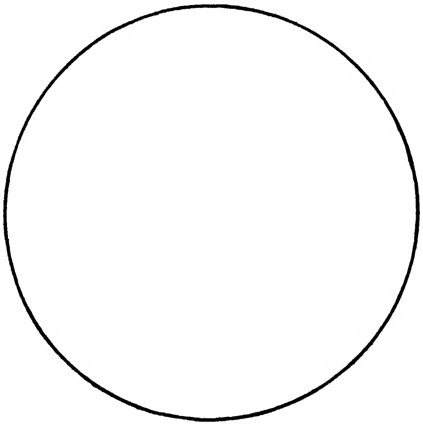

Fig. 3. - Perpendicular View of Saturn's Rings, A and B.

For convenience of reference, the three principal rings of Saturn have been designated by the letters A, B, and C. A is the exterior bright ring, B the interior bright ring (Fig. 3), and C the dusky crape ring. The dimensions of the two bright rings have been determined by several observers, whose results agree with fair precision. As showing the differences in the results, we give three series of measures* in the following table:—

	Struve.	De la Rue.	Jacob.
Outer diameter of exterior ring	40″·09	39″·83	39″·99
Inner diameter of exterior ring	35·29	35·33	35·82
Breadth	2·40	2·25	2·08
Outer diameter of interior ring	34·47	33·45	34·85
Inner diameter of interior ring	26·67	26·91	26·27
Breadth	3·90	3·27	4·29
Interval separating them ...	0·41	0·94	0·48
Distance of ring from ball ...	4·34	4·62	4·16
Equatorial diamoter of Saturn...	17·60	17·66	17·94

Expressed in miles, the figures, according to Struve, are:—

Outer diametor of exterior ring ...	169,526	miles.
Inner diameter of exterior ring ...	149,204	"
Breadth	10,160	"
Outer diameter of interior ring ...	145,762	"
Inner diameter of interior ring ...	112,758	"
Breadth...	16,503	"
Interval separating them	1,721	"
Distance of ring from ball	18,346	"
Equatorial diameter of Saturn ...	76,070	"

At the mean distance of Saturn, the linear value of a second of arc is 4,228 miles.

While the phenomena of the rings have been undergoing scrutiny, astronomers have sometimes noticed upon the sphere of Saturn one or more dusky bands lying parallel with the rings, and reminding one of the belts of Jupiter, though they are considerably fainter. They were first described by Cassini, who, while observing the division in the ring before referred to, saw on the planet's north side "a zone not far from the centre of the ring, and not much unlike the smallest of Jupiter's belts." But these appearances, though often observed, have not received critical attention; indeed, they have, in a measure, been lost sight of while the elaborate and attractive scenery of the rings has been under examination. The faint belts of Saturn deserve more notice than has been hitherto accorded them, for they are not only one of the most conspicuous details brought out by the telescope, but it is necessary that their appearances should be fully recorded, because they must exercise an important bearing upon questions relating to the physical condition of the planet. Whenever the belts are seen, their number, positions, and degree of distinctness should be severally noted, for if such observations became more general we might soon obtain evidence as to their persistent or evanescent character. It is certain, from the scattered descriptions we already possess, that these belts are a usual feature of the globe, lying parallel with the planet's equator; hence we may conclude that, from the analogy presented by the disc of Jupiter, they owe their origin to similar surface phenomena as that which is more abundantly and distinctly exhibited upon the Jovian planet.

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* "Monthly Notices of the Royal Astronomical Society," Vol. XVI.

Sir William Herschel found from observations in 1794 that this planet performed its axial rotation in 10h. 16m., 0·4sec., and this appears to have been the only value of the kind until, in December, 1876, Professor Hall, at Washington, detected a bright spot upon the ball of Saturn, which, by its successive returns, enabled him to fix the period at 10h. 14m. 23·8 sec., with a probable error of 2·3 sec., and without allowing for any proper motion or drift of the spot above the surface of the planet, for this luminous marking may have been purely atmospheric, and liable to movements independent of that given by the planet's rotation. But, were the spot a fixture on the surface, that is to say, a permanent feature of his physical composition, then its period must give a true value of the rotation of Saturn. It is this uncertainty as to the nature of planetary markings which renders it so difficult to fix with absolute reliance the times of rotation, though this hardly applies to the case of Mars, whose markings exhibit a degree of constancy, proving them to be the distant evidences of his material structure.

The moons of Jupiter were all discovered simultaneously by Galileo, in January, 1610, but the discovery of the eight satellites of Saturn ranged over a period of nearly 200 years. In the former case the objects were bright, and at once revealed in a small glass, whereas the Saturnian moons display a great difference in apparent brightness, so that while Titan, the largest, may be reached with an inferior telescope, the fainter one, Hyperion, can be glimpsed only with the aid of a large instrument, and under favourable conditions of the atmosphere. The discovery of the moons, arranged in chronological order, was as follows:—

No.	Name.	Date of Discovery.	Discoverer.
1	Titan	1655, March	C. Huyghens
2	Iapetus	1671, October	J. D. Cassini
3	Rhea	1672, December	J. D. Cassini
4	Dione	1684, March	J. D. Cassini
5	Tethys	1684, March	J. D. Cassini
6	Enceladus	1789, August	W. Herschel
7	Mimas	1789, September	W. Herschel
8	Hyperion	1848, September	Lassell and Bond

The periods and distances of the satellites have been ascertained as under:—

Number and Name.	Order of Discovery.	Periods.					Distances.	
		In D.	H.	M.	S.	In Days of Saturn.	Radii of Saturn.	Miles.
1 Mimas ...	7	0	22	37	23	2·16	3·36	120,800
2 Enceladus	6	1	8	53	7	3·14	4·31	155,025
3 Tethys ...	5	1	21	18	26	4·32	5·34	191,948
4 Diono ...	4	2	17	41	9	6·26	6·84	245,876
5 Rhea ...	3	4	12	25	11	10·34	9·55	343,414
6 Titan ...	1	15	22	41	25	36·49	22·15	796,157
7 Hyperion	8	21	7	7	41	48·73	26·78	963,300
8 Iapetus ...	2	79	7	53	40	181·53	64·36	2,313,835

The singular fact has been sometimes mentioned that the first (Mimas) revolves in half the period of the third (Tethys), and the second (Enceladus) in half that of the fourth (Dione). But it does not appear to have been noticed that the fifth (Rhea) revolves in about one-fifth the time of the seventh (Hyperion), and the sixth (Titan) in one-fifth the time of the eighth (Iapetus). The satellites of Jupiter also exhibit a degree of regularity in the periods of revolution. The first occupies half the time of the second, and the second half the time of the third.

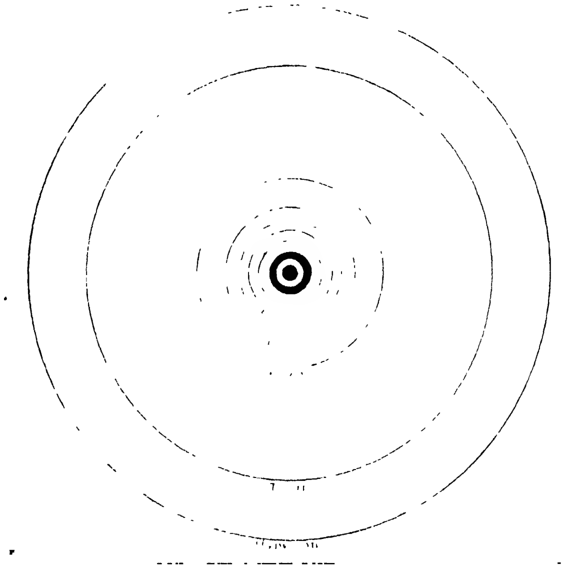

Fig. 4.—Orbits of the Seven Inner Satellites of Saturn.

The Saturnian satellites revolve in orbits (Fig. 4), coinciding with the plane of the ring, which is inclined about twenty-eight degrees to the ecliptic. But in the case of Iapetus there is a slight deviation, the inclination being about eighteen-and-a-half degrees. The satellite-orbits being thus inclined, have the effect of scattering the moons around their primary in a variety of different configurations, so that there is considerable difficulty in distinguishing them from small stars. The Jovian satellites are at once recognised in a row on the sides of the planet, but the moons of Saturn are spread around him indiscriminately, except at the time when the plane of the ring is directed towards the earth, in which case the satellites will conform to the line of the ring, and they will be perceptible, like those of Jupiter, on his east and west sides. There is another difficulty attending the observation of these minute objects, and that is their proximity, in several instances, to the ring of the planet. This particularly refers to Mimas and Enceladus, which, even at their extreme elongations, never depart far from the outskirts of the ring. When they were first detected by Sir William Herschel, "they were seen to thread like beads the almost infinite thin fibre of light to which the ring, then seen edgeways, was reduced, and for a short time to advance off it at either end, speedily to return, and hastening to their habitual concealment behind the body of the planet." Speaking of the seventh satellite (Mimas), its discoverer said:—"Even in my forty-feet reflector it appears no bigger than a very small lucid point."

The credit of discovering no less than four of the Saturnian satellites is due to Cassini, though the instruments of his time were of the most inferior and awkward character. The two satellites detected in 1684 were first seen with two object-glasses of 100 and 136 feet focal length, and afterwards by two others of 90 and 70 feet, made by Campani at Rome. They were used without tubes. Subsequently, the satellites were seen with a telescope of thirty-four feet and three and three-tenths aperture, and their periods calculated, so that they could be more readily identified afterwards. That Cassini, with his imperfect and cumbersome appliances, should have not only discovered these satellites, but also determined their orbits, is a sufficient proof of his skill as an observer, and shows that instrumental defects are in a great measure to be overcome by the zealous student of science.

The real dimensions of the satellites have not been ascertained with any trustworthy precision—obviously there are great difficulties in the way of deriving a correct estimate, for in the largest telescopes these bodies appear as extremely minute points of light utterly incapable of measurement. Titan, the largest, is probably superior to the moon in point of size, and his actual diameter has been computed at 3,300 miles, while that of Iapetus has been given at 1,800 miles. The others are considerably smaller, but the conditions of the case are, as we have said, opposed to the determination of the real magnitudes.

The satellites are liable to the same series of phenomena as those which attend the revolution of the Jovian satellites, being occasionally eclipsed or occulted by the body of the planet, and observers have sometimes noted the transit of the largest satellite, Titan, or its shadow, across the globe of Saturn. This occurred on several dates towards the close of 1877, but the varied configurations of the Saturnian moons, and the phenomena to which their motions give rise, are yet incomparable with what is presented by the Jovian system, which is discernible with greater facility and frequency.

Among the phenomena attending the revolution of Saturn, may be mentioned his occasional occultation by the moon. They are comparatively infrequent, however, and it is rarely that the weather allows a favourable observation. There were three visible occultations of Saturn in 1870, namely, on April 19, July 10, and September 30. The latter occurred soon after sunset, and was witnessed by the writer. The planet and moon were watched as they gradually approached each other, until, finally, the edge of Saturn's ring apparently touched the lunar disc, and both ring and globe soon disappeared from view, and remained invisible until nearly an hour and a quarter afterwards, when the reappearance of the planet was observed. The dull hue of Saturn contrasted strongly with the bright, clear light of the moon, but owing to the prevalence of mist, and the low altitude of our satellite, the phenomenon was not seen under the most auspicious aspect.

The rings of Saturn have naturally incited much speculation as to their physical character, and as to the purposes they were designed to serve in the economy of his system. No such appendage has been detected in connection with any other planet, and astronomers have been puzzled to account for a spectacle so unique and mysterious. The breadth of the double ring, including the opening between them, has been computed at more than 28,000 miles, but the width is extremely small, so that the most careful measurements have failed to give any satisfactory results, for when the plane of the ring is directed to the earth it becomes utterly invisible from its extreme thinness, and the most powerful glasses cannot reveal the narrow thread of light to which it is then reduced. Obviously, therefore, the rings are not comparable in point of bulk with the globe of the planet,* for though their breadth is considerable, they are of such marvellously small width that their thickness cannot exceed about 250 miles. That they are divided (and perhaps sub-divided) by open intervals of space is proved conclusively by the fact that stars have been seen through the chief division. Were the dark lines traceable upon the ring merely atmospheric phenomena similar to the dusky bands upon the planet, they would be seen under a different aspect. The permanent character and intense darkness of the chief division of the ring are sufficient to prove its real nature, and the fact has been long since admitted that there are, at least, two concentric rings, wholly detached, though of unequal breadth.

Sir W. Herschel computed that the bright ring performed a rotation in 10 h. 32 m. 15 sec., and it may be noted as a curious coincidence that Laplace had previously assumed a rotation in 10 h. 33 m. 36 sec. on theoretical grounds. But in 1854-6, Secchi, at Rome, obtained a result differing materially from Herschel's value. He gave 14 h. 23 m. 18 sec. as the period according best with his numerous measures. The question therefore remains in considerable doubt, for the great difference between the two values referred to seems inexplicable. It is probable, in the event of there being several wholly detached concentric rings, that the times of rotation may differ in the same ratio as satellites, so that the periodic time of the inner ring may be considerably shorter than that of the outer one. It therefore becomes necessary in an investigation of this kind to consider in what part of the ring the projections or peculiarities, from whence the rotation is deduced, were observed. In the case of a series of disconnected rings, each one may give a different rotation, according to its distance from the ball; but if the ring is solid and coherent in all its parts, then the period of rotation would probably be coincident with that of a satellite situated in the middle of the broad plane of the ring.

The constitution of the rings offers a theme for the indulgent exercise of speculative minds. That so remarkable and unique a phenomenon should preserve its stability, notwithstanding a rapid motion and the numerous disturbing forces to which it is constantly subject, is surprising enough, though when we consider the many wonders unfolded by the telescope we need not feel astounded that the complex mechanism of the Saturnian system should preserve an harmonious co-operation in all its parts. Seeing that the first indications of the ring were discovered not more than 270 years ago, we cannot say that this wonderful combination has maintained the same form and appearances through countless ages, and from the time when Saturn himself was first recognised as "a wandering star." Since the telescope has been applied so assiduously to celestial observations, no apparent changes of a physical character have been noticed, and the inference is that the present visible condition of Saturn offers no material contrast to his condition in remote antiquity. There the planet was, as now, circling amid his rings and satellites, though with unpretending lustre he gave no sign to natural vision of the gorgeous spectacle to be revealed by the telescope in modern times.

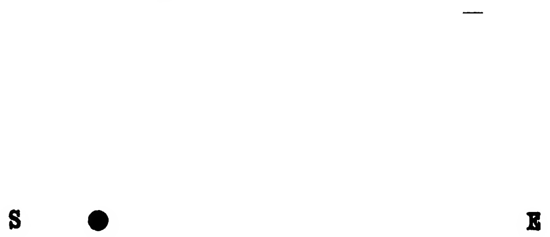

Fig. 5.—Relative Apparent Diameter of the Sun as seen from Saturn (S) and the Earth (E).

That the rings of Saturn are of the same material composition as the body of the planet is generally negatived on theoretical grounds. The American astronomer, Peirce, advanced the hypothesis that they "consist of streams of a fluid rather denser than water flowing around the primary." But Mr. Proctor rejects the supposition that they are continuous fluid rings, and concludes with Cassini that they are formed of a vast array of satellites, situated so closely together, and in such numbers, that at the immense distance of Saturn they appear to form a continuous mass. There are multitudinous zones of meteorites revolving around the sun, and the numerous discoveries of minor planets of late years show there is a thickly strewn zone of minor planets between the orbits of Mars and Jupiter, and these facts might be held to strengthen the satellite theory of Saturn's rings.

But it must be obvious that, if this is the real explanation of the rings, the satellites composing it are of extremely diminutive size, and infinitely smaller than the ordinary eight satellites of the planet, or the four satellites of Jupiter. Bond estimated the thickness of the rings as about 40 miles, and Sir John Herschel, in 1833, thought it could not exceed 100 miles, so that the best comparison we can offer is the miniature moons of Mars. A vast number of such bodies circulating in precisely the same plane, and in streams more or less disconnected, might give rise to the phenomena of the rings, but to our mind it conveys the impression of a solid structure lying (both in position and character) between the planet's sphere on the one hand, and the satellite organisation on the other. That it partakes largely of what is exemplified in the latter class of bodies, is certain from what has already been gathered of its physical peculiarities. It is greatly extended in the plane of the planet's equator, and revolves around him in the same theoretical period as that of a satellite placed at a similar distance. Moreover, it is disconnected into several concentric rings, each probably having a periodic time in proportion to the interval separating it from the planet. Thus, though the ringed appearance of Saturn cannot undeniably be regarded as formed of numbers of detached spherical satellites, it is evidently subservient to the same laws, and occupies a subordinate or satellitic position in the Saturnian system.

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* Bessell computed the mass of the rings at 1-118th that of the globe.

If the composition of the ring is of solid character, its equilibrium must be maintained, according to Laplace, by a rotation around the globe, and it must be separated into a number of rings, one outlying the other, and with different periods. Should its equilibrium be disturbed, it could not be restored, for it must be precipitated upon the ball of the planet, and thereafter form a coherent part of its substance. The most careful measurements show that the ring is slightly eccentric, the opening on the western side, between the ball and the inner edge of the interior ring, being less than that on the eastern side, and this oscillation of the centre of the rings about the body of the planet has been thought essential in controlling their stable equilibrium.

The extraordinary appearance of the rings in the firmament of Saturn must be of remarkable grandeur. In the daytime the sun will, it is true, obliterate its imposing effect, but as the evening comes in, and its brilliancy intensifies, it will present a spectacle which we cannot adequately figure to ourselves. As viewed from different parts of the planet, the appearances will be greatly diversified. Near the equatorial regions the rings will be seen as a vivid semicircle of light, spanning the sky. In the vicinity of the poles of the planet only a minor proportion of the rings will be visible; indeed, with every change of position the observer may trace new scenery, and the general phenomena of the rings and satellites will be of such frequent and varied character as to prove attractive in the highest degree. But to an inhabitant on Saturn the constant view of these wonders must lead to indifference, until at last they come to be regarded not as the wonders which the inhabitants of our planet consider them, but as the unattractive phenomena of Nature in her every-day aspect.

OLD SEA PENS.

By Chas. Lapworth, F.G.S., etc.,

Madras College, St. Andrews.

THE immense and well-arranged accumulation of knowledge which naturalists now possess respecting the structure and inter-relationship of organised beings, has been collected almost entirely within the last hundred years. It is true that several earnest and successful students of natural history lived and worked before the middle of the last century, and that many of our most important data had been already wrought out by them. But up to that time naturalists were few and far between, and their studies, regarded from our present standpoint, were ill-directed and ineffectual. As yet they had no standard by which to measure the comparative value of their several discoveries, nor guiding hand to point the way to the most productive methods of research. If we glance over the wide field of natural history of those days, we find it covered with a heterogeneous collection of crude materials and a multitude of disconnected facts, practically useless to the general student from the absence of the further knowledge how to make them available. The objects embraced in the study of natural history had not as yet been grouped in any single comprehensive arrangement, but to the eye of the average naturalist each organised creature seemed a friendless individual in a confused mob of natural objects. What was needed was a master-hand that would point out the true inter-relationship and mutual subordination of these facts—a Cæsar, as it were, in the republic of natural science, who would marshal this confused mob of beings into nations, into tribes, into hundreds and tens, and show us how to lead their well-disciplined battalions to the conquest of the entire realm of organised nature.

In all great crises in the history of mankind, when the time is ripe then comes the man. In 1736 an obscure Swedish physician, named Linnæus, published his celebrated "Systema Naturæ." At once, as if in obedience to "the stroke of a magic wand," the disorderly crowd of natural history objects fell into rank and file, and arranged themselves into regiments and companies, into families and genera. Linnæus found himself famous, and the future of natural history was assured.

In this notable work Linnæus reduced the confused array of materials collected by his predecessors to order and simplicity, and gave a clear and comprehensive view over the entire field of nature. From the highest to the lowest animals, and from the most complex flowering plant to the humblest fungus, all living creatures known to himself were arranged as closely as was then possible, in their natural order—each under the double title invented by Linnæus himself.

Nor did he stop there; for in those days mineralogy was regarded as forming a small branch of ordinary natural history, and Linnæus, following the fashion of his day, included an elaborate arrangement of rocks and minerals in his great work. In the mineralogical division of his subject he not only arranged all true rocks or minerals as we now understand them, but "fossils," or the petrified remains of living creatures, as well.

Now, of "fossils," Linnæus is careful to tell us that he recognised two distinct kinds—the "true" fossils and the "false" fossils. His "true fossils" were the "ichthyolites," "phytolites," &c., of the palæontologist, which are most distinctly the petrified relics of what once were living creatures. His "false fossils," on the contrary, were merely fossils in appearance, such as the well-known "landscape stones," "dendrites," and such-like, which the merest tyro in natural science is well aware have nothing in common with organic remains beyond their outward appearance, but are mere accidental markings, interesting only because of their quaintness and curiosity.

But in such a comprehensive work as his "Systema Naturæ"—which, of necessity, included *all* natural objects—Linnæus felt that even such obscure objects as these false fossils claimed a local habitation and a name. He accordingly dedicated an entire section of the mineralogical department of his work to their classification, and gave them the collective title of *Graptolithus*—that is to say, "figured stones," or "picture-fossils."

During the twenty-three years that followed the publication of the first edition of the "Systema," Linnæus, or the Continental booksellers, impelled by the universal demand for the book, put forth edition after edition; and so rigidly did its author adhere to his first definition that under the head *Graptolithus* every object noticed belonged of right to the group of false fossils. But in the year 1768 Linnæus unwittingly swerved from the correct path, and placed under *Graptolithus* two objects which we now know to have been true fossils. One of these is a well-known tree fern of the coal formation. The other had already been figured by himself in his "Scanian Travels," published eighteen years previously. Turning to that work, we find a rude engraving (see Fig. 1) of a curious marking found upon a slab of slate that had been broken in pieces, and which is described as resembling the impression printed by the edge of a milled coin. To this strange object Linnæus gave the title of *Graptolithus scalaris*, the "ladder graptolite."

Linnæus died in 1778, and as later naturalists have properly omitted the section devoted to the "false fossils" from the subsequent editions of the "Systema," in all probability the name *Graptolithus* would have sunk into oblivion but for an interesting discovery made in 1821. In that year the Swedish naturalist Wahlenberg had the good fortune to detect many examples of Linnæus' *Graptolithus scalaris* in the original localities in Scania. He saw at once that they were actually true fossils—the petrified remains of what had once been living creatures; and he suggested that they might be relics of ancient cuttlefishes, like the

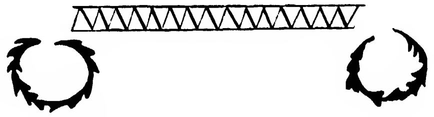

Fig. 1.—*Graptolithus scalaris*, Linn., the only true Graptolite figured by Linnæus.

Orthoceratites and *Belemnites* of the palæontologist. Within the next few years similar fossils were detected in Norway, Russia, Germany, Britain, and America; and it was then found that they occurred in extraordinary multitudes in every region where the older fossiliferous rocks are visible at the surface. These discoveries led to the resuscitation of Linnæus' old term Graptolithus, or Graptolites, and its application to the entire group of animals of which his *Graptolithus scalaris* is the type.

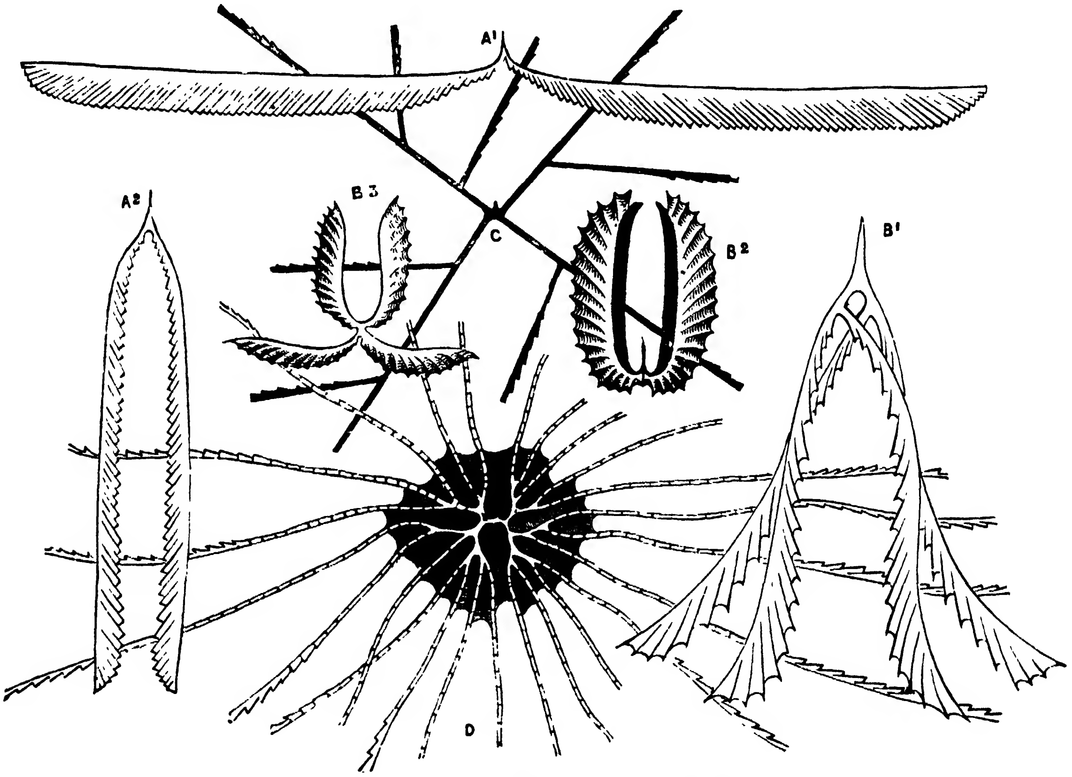

Fig. 2.—Group of Graptolites (*Dichograptidæ.*)
A², Didymograptus; B¹ B² B³, Tetragraptus; C, Temnograptus; D, Loganograptus.

As discovery progressed, the new material showed that Wahlenberg's theory of the cuttlefish origin of the Graptolites was unsatisfactory, but it held its own in the minds of many investigators till 1851, when it received its death-blow at the hands of the great paleontologist Barrande, who showed that the Graptolites were compound animals, like the Zoophytes, or plant animals, of our modern seas. But there are, as is well known, Zoophytes of many different types, and for a long time it was the fashion with some to regard the Graptolites as the allies of the Virgularia, or sea-pens, belonging to the class of the corals. Later evidences demolished this theory also, and at present it is believed that they are most nearly related to the very different sea-pens, or sea-plumes, the elegant Plumulariadæ, of the class of the Hydrozoa, and the "sea-pens" of the present paper.

When we look over a collection of Graptolites (Fig. 2) we find that they are all plant-like bodies, having their edges deeply notched. Some are leaf-like in their general form; others are long and slender. A few are quite simple, but the majority are branched, and of very complex structure. All, however, whether simple or compound, show the peculiar notches upon their edges; some having only one edge notched, others bearing teeth upon both margins. When they are in good preservation we notice that they must have been originally composed of some dark flexible substance, which is now transformed into shining carbonaceous matter of a deep black colour, beautifully relieved against the pale grey tint of the surrounding rock.

The simplest genus we know at present is called *Monograptus* (Fig. 3). Let us examine one of its commonest species a little more closely. Perhaps the most convenient form for our purpose is the *Monograptus Bohemicus*, of Barrande, shown in Fig. 3. In order to be of service it must be preserved with its full relief. When this is the case we see that the fossil is a long cylindrical or rod-like body, pointed below, and gradually thickening above. One side of it is formed of a row of deep cups placed one above the other in a continuous series (*a a*). Each of these cups has two apertures, one at the top of the cup opening outwards, and another at the bottom of the cup opening inwards into a long cylindrical tube or pipe which occupies all the central parts of the fossil. This central pipe is known as the "common canal" (*b*), and the lateral cups are called "calycles," or cellules. If we can get a glance at the back of the fossil we find in its outer surface a narrow groove running from end to end (*c*). Buried deep in this little groove we notice a minute rod, or thread, exactly filling it, and occasionally projecting from one or other of its extremities. This is termed the *solid axis*, or *virgula* (*d*).

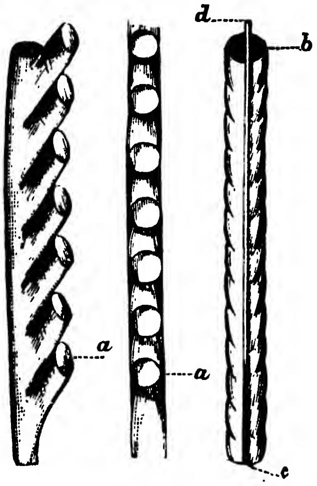

Fig. 3.—Monograptus Bohemicus (Barr) in relief.

a, Calycles, or Cellules; *b*, Common Canal; *c*, Dorsal Groove; *d*, Solid Axis.

If we now turn to any of the remaining forms of *Monograptus* (Fig. 5) we learn that they are formed precisely upon the same general plan. In all there is the pipe-like trunk with its series of cups in front, and its little groove filled by the slender "axis" at the back. The only differences distinguishable amongst them lie in the shape and arrangement of the calycles or cups, which vary in form to an extraordinary extent, becoming longer or shorter, hook-like, tube-like, and variously twisted and ornamented. Nor are the complex forms much less easy of comprehension, for they are plainly nothing more than branching structures composed of elements of the same general type as our original specimen. The forms with teeth upon both margins are at first sight much more difficult to understand; but, as first pointed out by Professor Nicholson, if we study some of them in relief, we find that they easily split longitudinally from end to end, and they have all the appearance of being simply two-branched forms, whose branches, instead of being free, are glued together, as it were, back to back.

In order to gain a correct idea of the possible appearances and mode of life of the Graptolites, let us turn aside for a moment and examine the structure of their living allies among the modern Zoophytes. Of these the group supposed to be most nearly related to the Graptolites is that of the Plumulariadæ—the sea-pen or sea-feather—a division of the so-called "sea-firs," which are not uncommon in the seas around our coasts.*

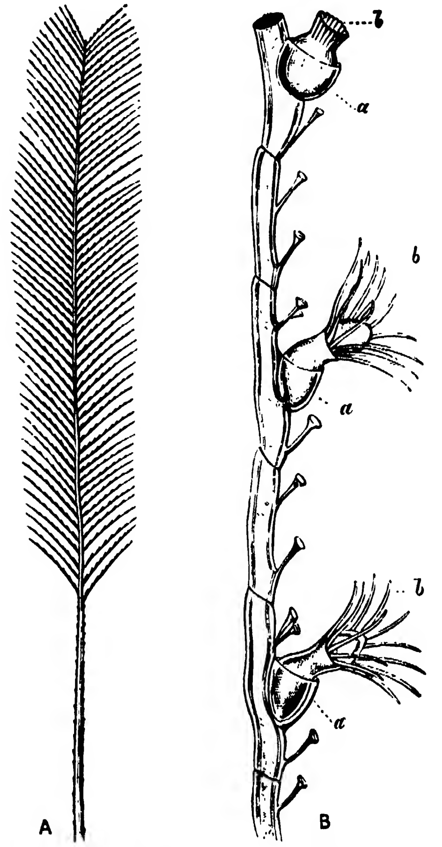

Fig. 4.—Plumularia, Modern Sea Pen or Sea Plume. (*After Allman.*)

A, Stem and Branches of a Species of Plumularia, natural size; B, Branch of Plumularia, magnified; *a a*, Calycles, or Hydrothecæ; *b b*, Hydranth, or Polypites.

In Plumularia (Fig. 4) we see a tree-like structure, very plant-like in its external aspect, and well justifying the old name Zoophyte, or plant-animal, bestowed upon it by the older naturalists. If we examine a single branch of it under the microscope, we notice that it is in truth a cylindrical horny tube. At regular intervals along its length are set little cups (*a a*), with wide apertures above, opening outwards, and narrow apertures below, opening directly into the central tube. If we study the creature in its living state, we see that each of these little cups contains a small living animal (*b b*), reminding us of the common fleshy Actinia, or sea-anemone, so abundant upon the sea-bathed stones of the shore. Like the sea-anemone, too, this little animal carries a circular fringe of tentacles, or long fleshy fingers, with which it agitates the surrounding waters, and brings within its reach the nutrient particles upon which it subsists. Through the minute aperture in the base of the cup the soft fleshy substance of each little animal is seen to be continued into the central tube, and this tube is filled with it from end to end. The entire structure is thus united into a single complex organism. The nutrient fluids collected by the several *polypites*—as the small creatures inhabiting the lateral cups are called—pass into this central tube, and circulate in regular periodic pulsations throughout the entire length and breadth of the colony, giving life and vigour and organic unity to the whole.

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* "Science for All," Vol. I., p. 378; Vol. II., p. 312.

The common flesh of this creature is called *sarcode*, and the central tube is termed the *cœnosarcal canal*. The cups inhabited by the polypites are called *hydrothecæ*, and the horny skeleton of the complete structure goes by the name of the *polypary*.

If we could by any means extract the whole of the living matter from our specimen Plumularian, it would be seen that the resemblance of the remaining horny skeleton to the Graptolites would be exceedingly close. It is certain that we have in these fossils the petrified hard skeleton, or *polypary*, of an organism resembling the sea-fir. The lateral cups seen in Fig. 3 (*a a*) were possibly hydrothecæ, each carrying a single animal of the colony. Through the exterior aperture of the cup it protruded its tentacles in search of nutriment; and through its inner aperture was prolonged the *sarcode*, or common flesh, into the central pipe or *common canal*, which was filled with it from end to end.

This comparison is satisfactory as far as it goes; but it is deficient in one most important feature. In the modern Hydroid Zoophytes we find nothing analogous to the solid axis of the Graptolites, and it is therefore impossible to unite the latter in the same group with Plumularia and its allies. For this reason they are usually regarded as forming a distinct and peculiar group, to which Professor Allman has given the title of Rhabdophora, or rod-bearers.

The special type of structure shown in the example of the branch of Plumularia is common under certain non-essential modifications to all the Hydroida of our seas. The polyparies constructed of this simple element, instead of being, as might have been expected, few in number, and of a monotonous character, are actually wonderfully abundant and diversified. They are all alike in the fact that each polypary has its own calycles, hydranths, and common canal, but they differ most remarkably in the form of the adult colony. Some are elegant and plume-like, others stout and bushy; some have but a single calycle, others have a population reckoned by millions. More closely studied, we find a beautiful order in the midst of this diversity. A certain unity of plan is seen to be present in special groups, which allows of their being divided by the naturalist into families arranged more or less according to their natural relationships; while each family breaks up in its turn into those subordinate groups which the naturalist calls genera, species, and varieties.

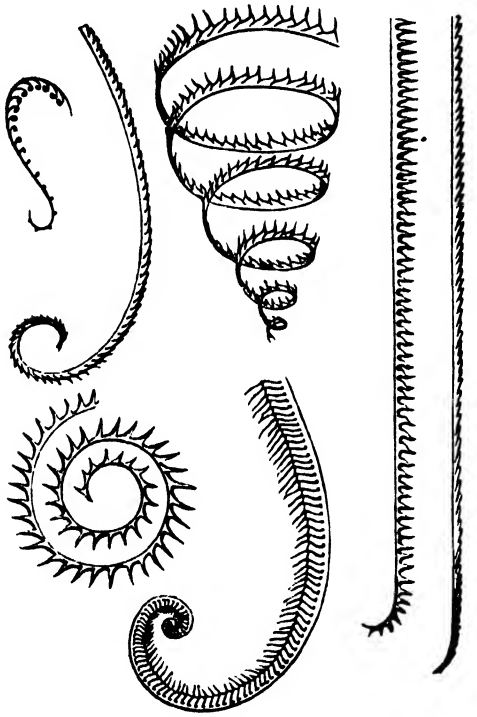

Fig. 5.—Various Forms of Monograptus.

Now, the ancient Graptolites admit of a detailed classification in precisely the same way. Not only have we species with a single series of calycles, as in Plumularia, but we find forms with two series placed back to back, and even species with four rows of cups. Some appear to have a single row of cups on the lower part of the stem, and a double series above; others, again, present us with a *stem* bearing a double series of calycles, and branches bearing a single series. With all these outward distinctions, however, there is a very intimate relationship between all these forms. To such an extent is this the case that it would be possible to connect the most extreme types by a series of intermediate forms, differing from each other only in a very slight degree.

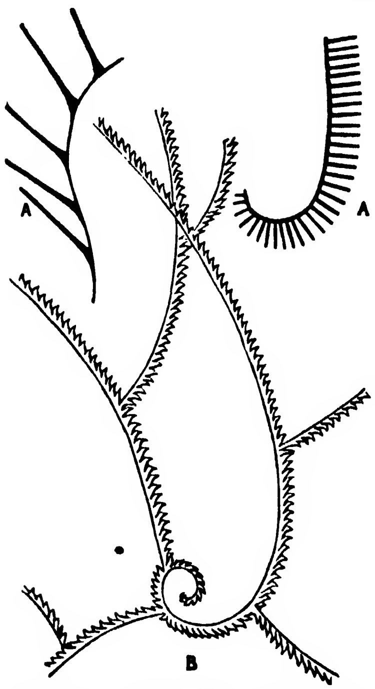

Fig. 6.—A A, Rastrites; B, Cyrtograptus.

When the study of these strange old fossils was in its infancy, naturalists were content to arrange them in the two groups of the Monoprionida (single saws) and Diprionida (double saws), according as they had one or two rows of calycles; but the abundant and richly-varied material collected of late years shows that this artificial arrangement is very inadequate. At present it is the rule to divide the Graptolites into "families," or large groups of forms, those being placed in the same family which appear to be the most closely related.

Commencing with the artificial division of the Monoprionida, or those in which the branches never carry more than one series of calycles, we find that the family which appears simplest in form and composition is that of the Monograptids (or single Graptolites), an example of which has been already described (Fig. 3). The three genera we place in this family in our collections are those shown in Figs. 5 and 6. The reader will notice that in all three the polypary is single, and carries but a single row of calycles upon its stem and branches. In Monograptus (Fig. 5) the cups all touch each other, but both they and the polypary itself vary strangely in shape. In some the cups are long and tubular, in others short and stout; here prolonged into a thorny spine, there curled into a rounded knob. Now and again the polypary is quite straight, but as a rule it is beautifully curved, either into a sickle shape, into a flattened coil resembling a watch-spring, or into a conical helix like the spiral of Archimedes.

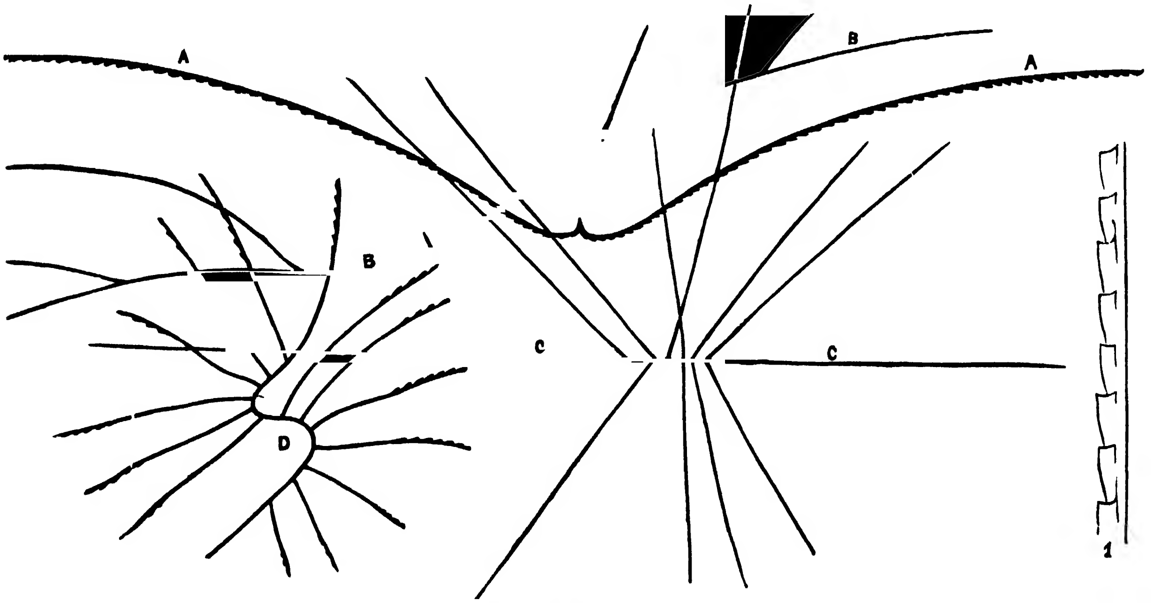

Fig. 7.—Leptograptidæ.
A, Leptograptus; B, Pleurograptus; C, Amphigraptus; D, Cænograptus; 1, Branch, magnified.

If we imagine a species of Monograptus as branching and rebranching again and again, we have its brother genus Cyrtograptus (Fig. 6, B) (Curled Graptolite), in which the elegantly curved polypary and differently-shaped calycles also recur. In the third genus of the family, viz., Rastrites (or the Rake Graptolite), the polypary carries no branches, but the cups are widely separated from each other, and are long and tube-like, standing upon end like the teeth of a rake (Fig. 6, A A).

The second family group is that of the Leptograptidæ (or slender Graptolites). The grand distinction between this family and the foregoing is seen in the fact that the polypary, instead of being simple and single, is actually two-stemmed and compound. All its genera again have the same kind of branches and calycles. The branches are long and slender, and the calycles are narrow tubes, pressed so flat against the branch as scarcely to be discernible without the aid of a lens. Though there are more genera in this family than in the Monograptids, there is actually less variety of form, because of the identity of the minor elements of structure. The genus *Pleurograptus* is one of the most conspicuous members of the family, occasionally forming a complete mat of entangled branches. The S-shaped Cænograptus is perhaps the most elegant genus, as Amphigraptus is the most crude in form, resembling the cracks made by a stone on a floor of ice (Fig. 7, A D).

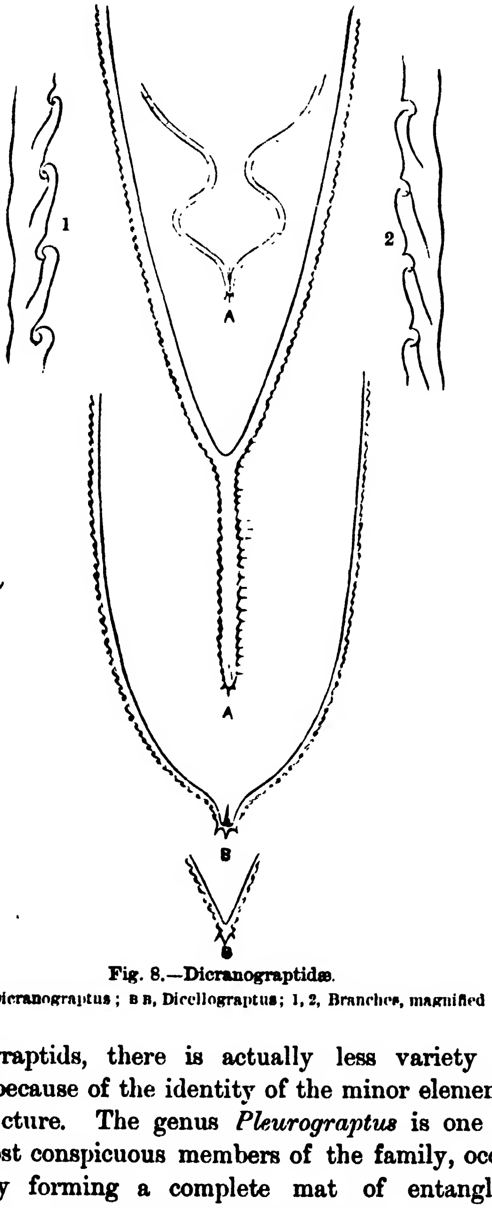

Fig. 8.—Dicranograptidæ.
A A, Dicranograptus; B B, Dicellograptus; 1, 2, Branches, magnified

Of all the families of the Graptolites, that known as the *Dichograptidæ* (evenly divided) is by far the most prolific (Fig. 2). Exactly as in the Leptograptids, the calycles are so invariable in shape that a fragment of a branch of any of the forms of this family is recognisable at a glance. Each cup is a long cone, widest at the mouth, but pressed slightly against its neighbours, so that it becomes somewhat wedge-shaped. The simplest form we know of at present is Didymograptus (twinned Graptolites) (Fig. 2, A), which is very like Leptograptus in its two-armed polypary, but is separable at sight by the shape of its calycles. All the remaining genera of the family are formed, so to speak, upon this element of Didymograptus. Tetragraptus (2, B) seems composed of two Didymograpti placed back to back. In Dichograptus each of the four arms, as it were, divides into two. In Loganograptus (2, D) each of these secondary branches divides again; and so on through a large number of genera, until as many as sixty-four branches are reached. But one point must not be forgotten. This repeated branching is nearly always regular in character. Each branch splits, as it were, into two in its turn, and the polyparies are regularly starlike and symmetrical.

The last of the single-rowed families is that of the Dicranograptids (two-headed). It includes at present two forms only, Dicellograptus (two-forked) and Dicranograptus. As in the last two families mentioned, the polypary in the present family is two-armed, and, like them, is distinguishable at a glance by the shape of its calycles, which are of a most peculiar construction. Each is actually sac-like in its general form (Fig. 8, 1, 2). The lower half of this sac is squeezed flat against the canal as in the second family, but the upper half is quite free. This free portion is bent somewhat into the form of a hook, and then thrust inward, so that the mouth opens almost against the common canal. Were no extra provision made, the polype in this family would have been a close prisoner for life; but nature, ever ready at expedients, has provided a means of exit by digging a deep hollow in the base of the succeeding calycle, and twisting round the point of the aperture slightly sideways. Thus the polype was enabled to protrude its tentacled head at pleasure, and when it was withdrawn it rested in perfect safety, buried in the deep hollow in which the cup-mouth was lodged.

In Dicellograptus (Fig. 8, B B), we find in the different species very great distinctions in the width of the angle made by the opening branches. As we go through the series we find this angle to become less and less, till, after a time, we find the branches practically parallel, so that they almost touch each other for some distance beyond their point of origin. When this is the case we frequently see the two branches united by a thin membrane to a certain extent, so that in some species the lower part of the fossil is two-rowed, and the upper part one-rowed, in the disposition of its calycles.

This leads us to Dicranograptus (Fig. 8, A A), in which this accidental feature becomes permanent and characteristic. In the lower part the fossil is clearly supplied with two series of calycles, while above the branches separate and the polypary becomes again monoprionidian, or furnished with only one series.

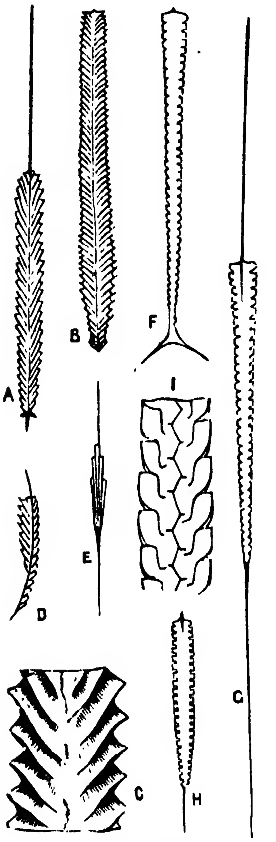

Fig. 9.—Diplograptidæ.

A, B, Diplograptus; C, Magnified; D, Dimorphograptus; E, Cephalograptus; F, G, H, Climacograptus; I, ditto, magnified.

Formerly, Dicellograptus and Dicranograptus were separated and placed in different groups. As our arrangement is to be a copy of that of nature, we now place them in the same family, for the two genera seem to run one into the other. There are, indeed, some species in which it is impossible to say that they belong to one genus more than the other.

The genus Dicranograptus, with its biserial stem and uniserial branches, leads us insensibly into the next great division of the Graptolites—the Diprionida, or biserial families; for it is clear that if the union of the branches were carried out to their further extremities we should get a form very like *Diplograptus*, the type of the biserial Graptolites.

In the Diprionida we find three families. The first is that of the Diplograptidæ, or double Graptolites (Fig. 9), which seem to be made of two single-celled forms placed back to back; for when they are well preserved we can split them down the middle into two longitudinal halves, each with its own canal and separate calycles, and supporting rod. In one of the genera (Climacograptus) of this family we find again the protecting hollows over the calycle-mouth, as among the Dicranograptids.

The second family is that of the Lasiograptids (shaggy Graptolites), which are remarkable for bearing strange ornaments upon their margins in the form of wicker-work, spurs, and spines (Fig. 10).

We next come to what is perhaps the most peculiar group of the Diprionida, viz., the family of the *Retiolitidæ*, or Net-graptolites (Fig. 11). In the genus Retiolites, which forms the type of this family, the whole of the surface of the fossil is covered with a beautiful coating, or cloak of network, or lacework, composed of fine black threads hardly visible to the naked eye. Underneath this veil-like covering we see the skeleton of a true Graptolite—the calycles, the solid axis, and the tubular common canal. But it is not possible to separate the two-rowed polypary into its two similar longitudinal halves as in Diplograptus, for the calycles have between them but a single common canal.

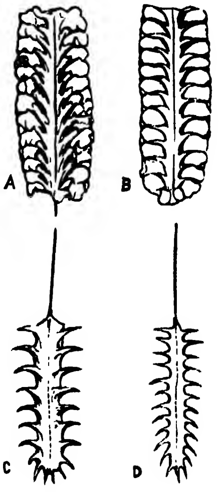

Fig. 10.—Lasiograptidæ.

A, B, Lasiograptus; C, D, Glossograptus.

Lastly comes the family of the Phyllograptids (Leaf-graptolites), in which the polypary actually consists of four calycle-bearing laminæ fitted together in the form of a cross (Fig. 13).

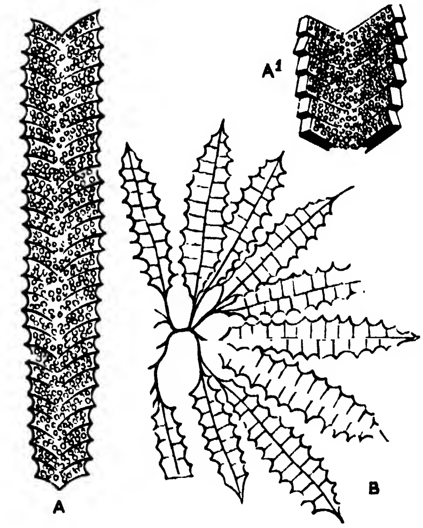

Fig. 11.—Retiolitidæ.

A, Retiolites; A^1, ditto, magnified; B, Retiograptus.

But it may be asked, How do these wonderfully complex structures originate? in what form are they first visible? and what are the several stages of their growth? To answer these questions, I must ask the reader to return with me to the modern sea-firs and Plumularia, and learn first what takes place among them, that we may know what to expect among the Graptolites.

The young sea-fir, after leaving the egg, is first distinguishable as an independent and exceedingly minute animal, called a *planula*,* of a flattened shape, a little thicker at one end than the other. Its surface is covered with vibratile cilia, and aided by their swift movement, it swims rapidly through the sea-water. After a time a thin, horny film grows over a portion of its surface, and the cilia disappear. When this happens, the little planula fixes itself to a rock or stone by its wider end. The narrow outer extremity moulds itself into a cup, carrying a hydranth, and this in its turn gives origin to others, until eventually the complete complex colony is developed.

It is clear that if the mode of development among the Graptolites was the same as among the Hydroida, the first stage of which it would be possible to obtain evidence would be that at which the horny film is formed over a part of the planula, for only the hard, horny portions of these fossils are preserved to us. Now, it is remarkable that at this special stage we actually get the earliest traces of the Graptolite, but how these traces stand related to the planula of the Sertularia we cannot yet say. Each Graptolite is first visible as a little conical sac—extinguisher-shaped—(Fig. 12, A) open at its wide end, and closed and pointed at the other. When compressed upon the stone, this little object has the form of a minute dagger—a little fibre projecting from its broader end forming the handle, and the compressed and pointed sac answering to the blade. Hence its name of sicula, or "little dagger."

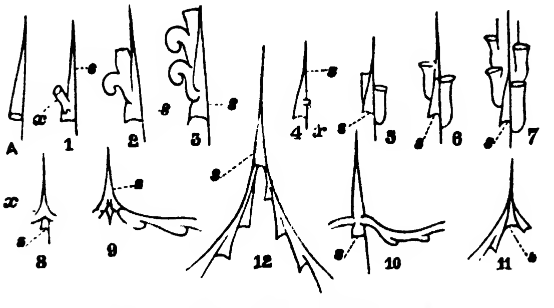

Fig. 12.—Development of Graptolites.

A, Sicula in its Free State; 1, 2, 3, Early Stages of Monograptus *x*, Primal Bud; *s*, Sicula: 4, 5, 6, 7, Early Stages of Diplograptus; 8, 9, of Dicellograptus; 10, of Cœnograptus; 11, 12, of Didymograptus.

In all the Graptolites whose mode of development has been fully studied, we find that the fossil makes its first visible appearance in the sicula form. After a time, a little bud grows out of the sicula near its broader extremity (Fig. 12, *x*). This is the commencement of the stem and common canal. In the bifid and compound forms this bud appears to be double; in the Monograptidæ it is always single. In Didymograptus the two branches which originate from the primal buds grow downwards and outwards at a wide angle, and the calycles are developed one by one as the branch lengthens (Fig. 12; 11, 12). In Cænograptus (Fig. 12; 10) they proceed horizontally, and the sicula stands upright midway between them, like a stiff spine. In Dicellograptus the branches bend backwards more and more, till finally, in Dicranograptus, they coalesce, and the sicula is buried up almost from sight in the bottom part of the stem. This is the case also in Diplograptus (Fig. 12; 4, 5, 6, 7). In Monograptus (Fig. 12; 1, 2, 3) it lies back upon the bottom part of the branch, to which it is tightly affixed by the whole of its extent.

Not only have we ascertained the mode of development among these ancient creatures, but we know something also of their methods of reproduction. Among the modern Plumulariadæ the reproductive elements are usually developed in certain sac-like bodies, which project outwards from the walls of the polypary, and similarly we occasionally find among the Graptolites marginal and terminal sac-like bodies of like form but vastly larger in size, which are by some believed to have been actually reproductive capsules. As a rule the reproductive sacs in Plumularia are naked and unprotected. Of late years, however, many new forms have been detected, more especially in the deep-sea dredgings carried on under the auspices of the British and American Governments, and in these recently-detected Plumularians the reproductive sacs are enclosed and guarded from danger in a most remarkable manner.

If the reader will turn to Fig. 4 he will notice between the hydrothecæ, or cup-like receptacles carrying the hydranths, certain additional calycles of very minute size. These are the calicetti, or *sarcothecæ*, of the zoologist, and they do not contain hydranths, but merely small processes of the jelly-like matter filling the common canal. In some of the Plumulariadæ referred to, a few of these sarcothecæ and branches are so modified as to form a basket-like receptacle of living wicker-work, inside which the reproductive sacs are safely enclosed, while in others long protecting fingers or spurs arch over the sacs for their protection.

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* "Science for All," Vol. II., p. 315, Fig. 7, D, &c.

It is probable that we have the counterparts of these protective processes in the wicker-work of Lasiograptus (Fig. 10, A B), and in the marginal spurs and processes found frequently among the Diprionidian Graptolites—an idea which gives some colour to Professor Allman's original theory that the marginal cups in the Graptolites correspond, not to the calycles in the Plumulariadæ, but to the minute sarcothecæ.

These resemblances between the Graptolites and Plumularians are very remarkable, as no true Graptolite is known to have outlived the Silurian system, one of the oldest of the fossiliferous formations recognised among geologists. In that system, as we have already stated, they occur in extraordinary profusion. The many forms we have enumerated, however, are not found mingled indiscriminately together in one and the same rock-bed; but in every region in which they have hitherto been detected they follow a determined rule of succession in time. Certain well-defined assemblages of families and genera always occur in association, and these special assemblages succeed each other everywhere in the same order. The lowest Silurian rocks have their special and peculiar group of forms; the highest Silurian is marked by a group totally distinct in every particular, while the intermediate divisions are distinguished each by its own intermediate but special group of species. To such an extent is this the case that the geologist knows exactly in what part of the Silurian he is working by the forms he collects.

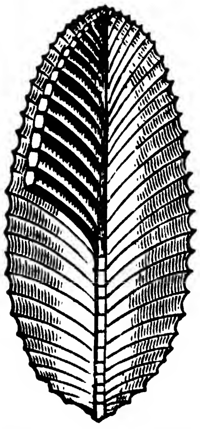
Fig. 13.—Phyllograptus.

The feathery Dichograptidæ and Phyllograptidæ (Fig. 13) are the first to appear, and in the earliest beds of the Silurian they are found in millions. As time goes on they gradually disappear, and their place is filled by slender Leptograptids and Dicellograptids. In the very middle of Murchison's Silurian system these also die out, and the double Graptolites, or Diprionida, which have been slowly increasing in number from the commencement, are found for a time alone. A little higher a few straggling forms of the simple Monograptidæ come into view. They rapidly increase in numbers as we go up the rocks, while the Diprionida decrease, and after awhile seem to become wholly extinct. In the higher Silurian rocks the Monograptidæ reign alone, but before the system is closed they also vanish, and no Graptolite has ever yet been met with in rocks of later age.

This wonderful variation in the grouping of life-forms as we pass upwards through the succession of rock-groups—from the earliest dawn of existence to the latest deposit with which the geologist has to deal—is one of the most striking, and at the same time one of the most mysterious of the phenomena the palæontologist meets with in his researches. In the pages of the history of mankind we watch with interest the alternate rise and fall of the waves of change. One after another, some small tribe thrusts itself into prominence, subduing and absorbing its weaker neighbours, rising slowly to its highest pitch of power and dignity, and thence as slowly sinking back again to insignificance and oblivion. We can follow it upwards, step by step, and thence as clearly downwards in the inevitable course of disintegration and decay. Though the mists of time hide much from our sight, we catch nevertheless, at intervals, clear indications of the cause of these changes. Free from the blinding influences of personal interest and the distorted view which necessarily accompanies immediate proximity, we watch from a distance, and with unimpassioned eye, the inevitable sequence of cause and effect. But in the gloom which enshrouds the history of the life-forms studied by the palæontologist, all but the faintest glimmering of light is as yet wanting. The correspondent changes are certainly there—the stages of origin, culmination, and decay; but of the true causes of these changes we are as yet profoundly ignorant. To the sage astronomer, the proper motions of the so-called fixed stars, and the form and characteristics of the nebulæ, whose misty light travels to us from regions of space inconceivably remote, are demonstrative that the physical laws that reign in our planet extend their rule to the farthest limits of the visible universe. In precisely the same way the development and mode of growth of these ancient Graptolites, and the direction and proportion of the changes they underwent, are demonstrative to the naturalist that the laws which now regulate growth and development in the animal world have remained substantially unmodified since the dawn of existence.

DIGESTION.

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FOR the more fortunate among us the process of digestion of food is a simple enough affair; and neither the difficulties of effecting it, nor the state of mind which almost inevitably accompanies any difficulties in this matter, lead to what is justly taken to be a breach of good manners, namely, any reference to the process at all. To turn aside for one moment, we may point out how curiously any reference to the matter is, like other references to many other similar concerns, out of good taste; it is because when digestion is not good the difficulties that are associated with it are not confined to the sufferer, but extend to all those with whom he is brought in contact. It may be true that nothing is more painful than a failure on the part of the digestive organs to do their duty; but it is no less true that of all the material causes which injuriously affect society, to none can more harm be ascribed than to this, and the trite saying that success in life is largely due to a good digestion must be ascribed to a wise physiologist, or to a most unhappy victim. It is either the voice of wisdom crying in the streets, or it is the bitter wail of an unwilling sufferer.

From the personal and social view, therefore, a knowledge of the processes of digestion is very far from being unnecessary; a careful study of this everyday arrangement may, perhaps, be able to lead us, as every investigation into natural phenomena should, to some more general views of the fundamental laws which, impressed on living objects, are a sign of the mode in which what we call Nature effects the purposes and creates the possibilities of existence.

The difference between minerals or non-organised matter, and vegetables and animals, or organised matter, has been often dilated upon; but the reader must again be reminded of the salient point. When a mineral, such as a crystal of sulphate of lime, grows, it does so by depositing layer after layer of fresh sulphate of lime outside that already formed; the new substance *does not enter into the composition of the parts of the original crystal.* With organised matter the process is entirely different; matter taken in from without is, as a rule, first converted into matter exactly similar in character to the organism into which it enters, and the new substance *is stored up in parts of the original living substance.* This prime difference depends on two causes: first, the organised matter exhibiting activity uses up part of what already forms a portion of itself, which is not the case with the crystal; secondly, the crystal takes up only substances which are chemically of the same character as itself, while the man, the snail, the rose, or the fern, which do not find substance exactly similar to the nutriment of which their various parts are composed, have to convert into such substance foreign bodies. This conversion is either effected quite simply, the animal taking the food at once into its general mass, and there making it like the rest (Amœba); or by more and more gradual stages of elaboration, a part of the body—the digestive organs—is set aside for digestive duties; when this is carried to that stage of complexity which is found in ourselves, the extreme result is arrived at, that a wall of partition, by its especial physical characters, prevents the food from passing into the blood-stream till it has undergone special changes within the digestive cavity.

Leaving then, for the present, plants on one side, we find that animals either take nutriment *en masse* into their general body, or set apart special agencies—stomach and so on—for converting it into special bodies, and other organs—blood system and so on—for carrying it to the different parts where activity has entailed loss of tissue, and where loss of tissue requires renovation.

In dealing with subjects like the present two courses are open to us, both of which have much to recommend them: the first, and the better, is to begin with the simplest of all organisms, and step by step to work our way up to the most complicated; this is the only scientific method. The other is to commence with what is known, or, we fear we must say, supposed to be known, and gradually to work away till we reach what is unknown; this is the more agreeable and attractive course, and is one which is founded on the peculiarities of our nature. Just as a pin-prick in ourselves is more terrible than a massacre in China, so the processes of digestion, complex as they are in ourselves, will find more students than the far simpler methods in use among the animalcules. To begin, therefore, with a description of the structures and uses of the organs of digestion in man.

First, we have organs for seizing and grinding down the food—the lips, the muscles of the jaws, the teeth; and then we have the organs which pour out secretions, by the action of which the food is changed in chemical character—the salivary glands, the glands of the stomach, the bile, and so on; and finally there are the circulatory systems which convey this changed food away to its proper storehouses or to failing parts.

With regard to the teeth it is unnecessary to say anything more,* save only this—that their function as grinders, as the organs by which the coats of vegetable cells are bruised and broken, is not always sufficiently taken into account; envelopes of various kinds on various bodies are unharmed by the action of the gastric and other juices, the chief duty of which is to act on the contents within these envelopes. Herein lies the *rationale* of mastication.

The function of the lips is not in man, save in the suckling-baby state, very considerable; not considerable, at any rate, as compared with the function that they have to perform in grass-eating animals; but though this duty has been greatly lost by them, and been replaced by the higher function of aiding in articulation, the nerves which go to their muscles go also to other parts which still have important duties in the process of digestion, while their own function as the seats of sensibility is not to be lost sight of. When the jaw has been lowered, partly by its own weight, partly by the muscles which depress it, the parts just referred to come into play. The nerves which go to the muscles are branches from the seventh or facial nerve, and from the lower half of that fifth nerve which we spoke of in a previous paper † as being the spinal nerve of the head; this latter supplies the three chief muscles which raise the jaw—the *masseter*, or chewing muscle, and the temporal and pterygoid muscles, which receive their names from the bones of the skull with which they are connected. The mode of action of these structures will be easily understood by a reference to the adjoining figure (Fig. 1), where *ip* marks the internal of the two pterygoid muscles, and *m* the masseter; the temporal muscle, which is not seen in this figure, is inserted into the inner face of the lower jaw-bone. Branches from the seventh pair are sent to some of the muscles which depress, or lower, the jaw.

The muscles already named act generally in raising the jaw; the external pterygoid (*ep*) has a somewhat more complex action; it is so attached that, when it contracts, it draws the hinder part of the jaw forward; and, as matters are so arranged that, as a rule, only one contracts at a time, it will be clear that the jaw will be a little drawn to one side, and this lateral movement, in which other muscles also take some share, is the means by which the grinding action of the molar or grinding teeth is effected.

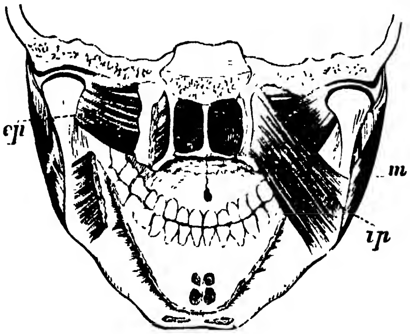

Fig. 1.—Some Muscles of the Jaw.

We have said that other parts are affected by the nerves which go to the muscles already referred to, and by this we have somewhat anticipated our account of the influence of a branch of the seventh nerve on the organs which are the next to come into action during the process of digestion. It is hardly necessary to say that we refer to the *salivary glands*, by the secretion of which the mouth is moistened, and part of the food altered in chemical characters, as has been already explained in an elementary manner in a former paper, ‡ which, as bearing on our subject, we shall now supplement by additional remarks. The nerve in question is a branch of the seventh pair, and as much of the processes of secretion has been learnt from a study of its influence, we must remind our readers that technically this branch is known as the *chorda tympani*.

First, however, we must learn to know the salivary glands themselves. Of these there are three chief pairs, set on either side, and known respectively as the *parotid* gland, the *sub-lingual*, and the *sub-maxillary* or gland below the inferior maxilla (lower jaw). These glands are all provided with efferent ducts or canals, which open into different parts of the cavity of the mouth; the parotid duct has an orifice above the second molar tooth of each upper jaw, the duct of the sub-maxillary (Wharton's duct) opens close to its fellow, below the tongue and at the point where that mobile organ is attached to the membrane beneath; the sub-lingual has a number of ducts, which open into or near the duct of Wharton. With regard to the glands themselves, we need only say that they are constituted by a number of lobes, so that they have, broadly speaking, a grape-like, or, to use a more technical term, a *racemose* appearance, and that in man the parotid is the largest; but the parotid is not always the largest, and the secretion of the fluid poured out from the glands is not always so nearly similar as it is in ourselves; this is best illustrated by a reference to the ant-eater, a magnificent specimen of which is in the gardens of the Zoological Society of London, where a careful observer may make out its mode of eating; the secretion from the sub-maxillary gland of this animal is excessively thick, and has been not inappropriately compared to bird-lime; this thick secretion lies on the tongue, and the animal, protruding that organ, is enabled by this slime to catch for itself the insects on which it feeds.

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* "The Teeth," "Science for All," Vol. II., p. 156.

† "Taste," "Science for All," Vol. III., p. 108.

‡ For a further account of the chemical characteristics of saliva, see "Science for All," Vol. III., p. 306.

The action of the saliva or secretion of the glands is in man, and indeed in very many of his allies, of very considerable chemical activity. Much of the food which we eat, such as bread, potatoes, and so on, contains a quantity of starch; now, as we all know, starch cannot pass through that wall which separates our internal chemical laboratory from the blood or circulating medium, by means of which the different tissues obtain the nutriment they require, and it must therefore undergo a change in character. Here we come to one of the more general propositions to which a study of the digestive processes leads us; to a consideration, that is, of those fermentative processes, by means of which a small quantity of matter is enabled to effect great changes in the bodies with which it is brought into contact. How great this effect is, may be imagined by a knowledge of the fact that in two hundred parts of human saliva, not so much as one part is solid; or, to put the matter still more strongly, many competent observers have found more than nine hundred and ninety out of a thousand parts of mixed saliva to be nothing but water. On the other hand, we all know what a little yeast will effect in a mass of dough, and to the minds of all will the words occur "a little leaven leaveneth the whole lump."

Between the fermentation of the yeast-plant and the ferment-activity of the saliva secretion there is, however, an important difference: with the former we have a distinct and definite organism, the presence of which can be easily demonstrated under the microscope; here we have to do with an organised or so-called morphological ferment; and the processes to which the name of fermentation are applied belong primarily to this class. In the case of saliva there is no such organised ferment, and all that we know of the mode of action is, that for saliva to be able to convert starch into another body, it is necessary that it should contain a definite substance; without entering into all the experiments by means of which the characters of this body have been proved, it is only necessary to say that after filtration of the saliva, and after treatment of the filtrate with alcohol, a substance can still be dissolved out by water, which is just as active as fresh saliva; to the substance thus obtained the name of *ptyalin* has—we have already learned (Vol. III., p. 306)—been given; when dried *in vacuo* it appears as an almost pure white powder.

To understand its mode of action it will be necessary, first of all, to know the chemical constitution of the starch, and of the grape-sugar into which the starch is converted;* both these bodies consist of a number of atoms of carbon, hydrogen, and oxygen, and the chemical formula of the one may be most simply written thus: $C_6H_{10}O_5$ and of the other—the grape sugar, $C_6H_{12}O_6$ and the difference between these two bodies lies in the fact, then, that grape sugar has two more atoms of hydrogen, and one of oxygen, than has starch. All the readers of this work know that H_2O is the chemical formula of water; we may then conclude that what ptyalin does is to mix with every molecule of starch one molecule of water; that this is done directly is not to be supposed, but this is the effect of the change. Here, then, is the first great change which food undergoes; chemically speaking, the starch is hydrated, physically speaking, it is converted into a body which is capable of passing through the membranous wall of the stomach or becomes diffusible; to this we will return later on.

Although saliva has in man this remarkable activity, the function of the fluid as affording a supply of water, and water at a temperature very nearly that of the body, is one which must not be overlooked; no better example of this use of the saliva can be observed than in the Carnivora, where the food is swallowed almost as soon as it is taken into the mouth; nor in these creatures is the action of the secretion nearly so rapid as it is in ourselves.

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* The chemical characters are to be detected by experiments, of which an account is given in "Science for All," Vol. III., p. 307.

If other examples of the value of salivary glands as water-organs are needed, they are to be found in the great development of the parotid gland in the kangaroos which dwell in the arid plains of Australia, and in their absence in the whales and dolphins. Nor, on the other hand, must it be supposed that this mode of ferment-activity is confined to the saliva, or to other secretions of the animal body; the starch stored up in vegetables is primarily stored up by them for their own use, and when they need it, it may undergo conversion into grape-sugar, and enter more directly into the composition of the plant; and, again, from germinating barley, ground and treated with water, a substance capable of converting starch into sugar has been obtained and, as Professor Schutzenberger reminds us, there is in almonds a body capable of converting the contained amygdaline into essence of bitter almonds. This non-organised ferment stands, moreover, mid-way between such organised ferments as the yeast plant, which we have already referred to (Vol. I., p. 51), and those still more complex agencies which take up oxygen only to give it up again; of these even more purely chemical agencies, spongy platinum is perhaps the best example; while another, not unknown to the manufacturer of sulphuric acid, is the curious part which is played by sulphuric dioxide.

We come now to the changes which occur in the salivary glands themselves, where we shall be able to learn something of what is known as to the process of secretion. The easiest way, perhaps, to grasp this matter is to look upon the living gland as much the same as a living animal; that it should do its work it must be fed, and to rouse it to do its work it must be subjected to nervous excitation. The nervous connection is said by the eminent German physiologist Pflüger, to be so close that a nerve-branchlet passes to the constituent cells of the salivary gland lobule; this may be true, and Pflüger's figures, of which one is here reproduced (Fig. 2), go a long way to confirm the statement; but it is one which has not been very generally accepted.

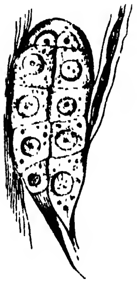

Fig 2.—Nerve Passing to Salivary Gland-cells.

In any case the nervous influence is marked enough, as may be seen by exciting that nerve-branch, the chorda tympani, which we have already mentioned; when this nerve is excited, the flow of saliva from Wharton's duct, the duct of the sub-maxillary gland, is considerably increased; this flow is preceded by two phenomena, one of which is from the nature of things very much more obvious than the other: they are (1) the increase in size of the cavity of the arteries, owing to the dilatation of these vessels; with this is connected a more rapid flow of the blood-stream, and consequently the passage of a larger amount of blood through the gland. (2) The other is a series of changes in the cells of the gland itself; it is clear that these changes are at any rate partly due to the greater amount of food, so to speak, which the increased blood-supply affords. If Pflüger's observations are correct, it will follow that in addition to this extra feeding, another cause is to be found in the changes which take place in the cell itself.

Without going any further into this complex and difficult problem, we may say that the question really resolves itself into this: is the secretion of saliva merely a filtration through the gland, or is the gland itself an important agent in the manufacture of the saliva? In answer to this we will give one short quotation: "If the head of an animal be rapidly cut off, and the chorda immediately stimulated, a flow of saliva takes place, far too copious to be accounted for by the emptying of the salivary channels through the contraction of their walls. In this case secretion is excited in the absence of blood supply."*

To sum all this up, the salivary glands of man, in addition to moistening the mouth and diluting the food, secrete a substance which converts starch into grape-sugar; this secretion is accompanied by an increased supply of blood to the parts, and by changes in the cells which make up the gland. During life this secretion, which never completely ceases, is increased by a nervous excitation, which is reflex, or brought about unconsciously by the presence of food (or of other bodies) in the mouth. The presence of this food is signalised to the brain by the sensory nerves which are supplied to the mucous membrane of the mouth and tongue (Fig. 3, Vol. III., p. 308).

We must now pass on to the other changes which the food undergoes elsewhere after it has gone through the complex process of being swallowed. Having passed down the gullet or *œsophagus*, the food comes to a somewhat capacious sac, which is the stomach, and here that part of the food which is albuminous, such as meat, eggs, and so on, undergoes its most important changes. We will first direct attention to the mode by which it becomes diffusible.

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* M. Foster: ' Physiology," p. 182.

Some years ago, the illustrious chemist, Thomas Graham, who was for many years Master of the Mint, pointed out that bodies might be arranged in two series: they might be capable of diffusing through a membrane—these are crystalloids; or they might be incapable of so diffusing—these he called *colloids*,' for gelatine may be taken as their type, and *kollé* is the Greek for jelly. Now, if we take some raw muscle (flesh), or cooked meat, and mince it up small, and treat it with water, and place it in a hoop-shaped glass vessel, closed on one side by a piece of membrane, and place this in a vessel of water so arranged that the level of the surrounding water is not as high as the upper rim of the hoop-shaped vessel, we shall find that nothing will pass through the membrane; that all the minced meat will remain in the smaller vessel, and all the surrounding water will remain quite pure; and we shall further be able to detect no change at all till the meat gives evident indications of putrefaction. But, if instead of this simple arrangement we add a little of the secretion of, say a pig's stomach, to the meat, and add therewith a little dilute hydrochloric acid, we shall, especially if we keep the vessel at a temperature about equal to that of the body (say from 95° to 100° Fahr. or from 38° to 40° C.), find in a very short time that the water is not pure water any longer, and that by the aid of appropriate chemical agents we can discover in it bodies which are known as *peptones*, and which receive their name from the fact that they have been acted on by the *pepsin* of the pig's stomach.

To make this matter still clearer, we will describe a few experiments, the result of which will be to show, that by the agency of this pepsin and acid, the colloidal meat has been converted into a diffusible (dialysable) body.

Our pepsin will have been thus prepared: a small piece of the mucous membrane of a pig's stomach will have been cut into very small pieces, and after being dried with blotting paper, will have been placed in a bottle and covered with strong glycerine; a few hours afterwards this "glycerine extract of pepsin" will be fit for use. Taking now three test-tubes, into one we place a little prepared meat-stuff with a few drops of the glycerine extract; into another we place some meat-stuff and some very dilute hydrochloric acid; and into a third we place the meat-stuff, the pepsin, and the dilute acid. When we come to test these, either by the dialysing membrane already spoken of, or by certain chemical re-agents, of which more shall be said directly, we find that no change has occurred in the first or second tubes, although they, like the third, have been subjected to a temperature sufficiently near that of the body. In the third test-tube peptones will be found.

From this series of experiments we may learn, that in the pig (and the same is true of ourselves) peptic juice and a dilute acid must both be present, to effect digestion of what has till now been called meat-stuffs; by this last term we have meant to speak of albuminous bodies, or of bodies in which the chemical element, nitrogen, is always associated with the three elements, oxygen, hydrogen, and carbon, which we found in starch or cane-sugar.

In the detection of peptones, or altered albumens, we may make use of a large number of chemical tests; here we will mention only the most obvious. As we all know, boiling water effects a great change in white of egg; when this is placed in boiling water, or subjected to a high temperature, it curdles and hardens; this is not the case with peptones. Nor are they thrown down from their solution (precipitated) by strong nitric acid; which, as most of us know, very rapidly gives a yellow tinge to fresh albumen; with tannic acid peptones give a reddish-brown precipitate, and with mercuric chloride one which is of a yellowish colour.

We have not the space here to linger any longer over this, the chief function of the stomach proper; an organ which has been defined to be one which is capable of dissolving albuminous bodies; but before passing on to the consideration of its structure in man and other animals, it is necessary to link it with what we have learnt about the influence of saliva. From the secretion of the stomach, just as from the secretion of the salivary gland, it is comparatively easy to obtain a body which, indefinite in form, is not an organised ferment, and yet which has very strongly-pronounced ferment-activities. Its resemblance to the yeast and other ferments of the organised kind is nowhere more strikingly shown than by the facts, which we have learnt, as to the extremely minute quantity of it which is required for the successful performance of its duties. The action and origin of the acid are involved in greater obscurity, but the necessity for its presence is often enough demonstrated in individuals, and can always be shown in experiment.

What now is the stomach itself? From a general point of view, it is an internal chemical laboratory, which never lets the meat-stuffs pass through its walls till they have undergone changes at its hands. In man it is a sac which lies transversely across the long axis of the digestive tract (Fig. 3), has one orifice towards the right, and another towards the left, and both on its upper surface; it is so arranged that one curvature is very much greater than the other, and that a blindly-ending sac is found on the left side. Varying somewhat in size at different times, it may be generally said to be from ten to twelve inches long, and about four inches broad. Its walls are of a not inconsiderable thickness, and of its four layers there are two which are, for our purposes, of the most importance; the one is the muscular coat, thanks to which the churning movement of the contents is kept up, and the other is the coat of mucous membrane, in which we find the glands which promote its secretions. All these coats are shown in the subjoined figure (Fig. 4;) where *a* represents the glands, and *d* and *e* two of the muscular layers; the upper one is known as the transverse, and the lower as the longitudinal layer; the third layer, in which the fibres run obliquely, is not as regularly disposed as the other two, and is not seen in the figure here given.

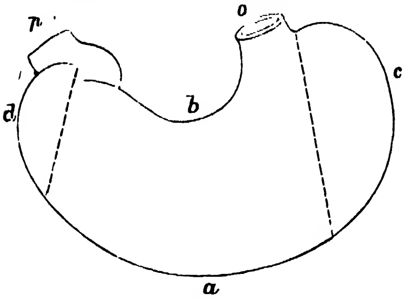

Fig. 3—Diagram of the Human Stomach.
a, Greater, *b*, Lesser Curvature; *c*, Cardiac End; *d*, Pyloric End.

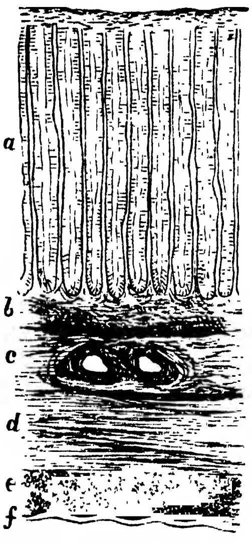

Fig. 4.—Section of the Wall of a Pig's Stomach.
a Glands; *b*, a Muscular Layer; *c*, Submucous Layer; *d*, Circular; *e*, Longitudinal Muscular Layer; *f*, Outer Coat.

By the aid of a simple hand-lens, it is possible to see the orifices of these glands on the inner face of a stomach which has been laid open; in section the glands are, as the figure shows us, tubular in form, and end blindly at their lower ends, even when that end is, as it is sometimes, branched into two or three or even more, processes. The *epithelial* cells which line these tubes are when simplest merely columnar in form, as is roughly indicated in Fig. 4, but is better seen in Fig. 5, which gives a more highly magnified representation of one of these glands. Here we see (Fig. 5.) that the columnar cells are found only in the upper portion of the gland, and that the greater part is occupied by larger and more or less rounded cells, which fill up the whole of the cavity of the tube; these last are known distinctively as the peptic cells, and, in some animals at any rate, it is only by the aid of parts of the stomach in which these cells are present that gastric digestion can be effected artificially.

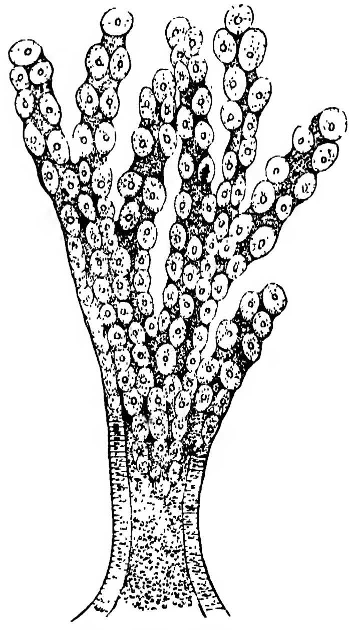

Fig. 5.—Gastric Gland, the upper end looking downwards, × 100.

Let us work this out a little further. It is probably known to all our readers that the stomach of those quadruped animals which ruminate or chew the cud is very much more complex than that of man; it is, in fine, divided into four compartments, into two only of which the food passes, before it has been returned to the mouth to undergo the leisurely and complete mastication which takes place during rumination. How complex it is the accompanying figure (Fig. 6) will show; to the right of the reader there will be seen an enormous sac which ends blindly, and is obviously enough the greatly-dilated cardiac portion; where this joins the œsophagus (*a*) there is a smaller, irregularly quadrate cavity, which is in free connection with the great *paunch* (*b*), and this cavity, from the arrangement of its mucous membrane, is known familiarly as the *honey-comb*, and technically as the *reticulum* (*c*); as the figure shows, the passage into the next division is extremely narrow, but what the figure does not show is indicated by the name of the part: it is called in English the *manyplies*, and in technical language the *psalterium* (*d*); the former name indicates its possession of a number of folds, while the latter tells us that these folds are closely packed one against the other like the leaves of a book; the particular name chosen may well be kept, because it reminds us that the name was given by the old anatomists, to whom the psalter was the most common of all books, and perhaps the only one

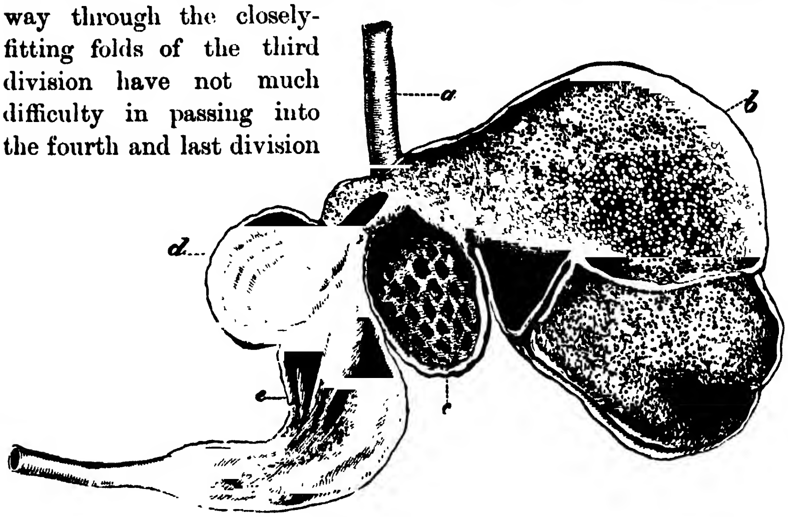

Fig. 6.—Stomach of Ruminant.
a, Œsophagus; b, Paunch; c, Reticulum; d, Manyplies; e, Rennet-stomach.

possessed by those whom they were addressing; this psalterium is connected by a groove directly with the gullet. We can easily enough imagine that bodies which have been able to make their way through the closely-fitting folds of the third division have not much difficulty in passing into the fourth and last division of the stomach, which is the only portion in which the peptic glands are developed, and which, therefore, is used in making cheese, for by it the milk is made to curdle or to run; thence it is popularly known as the *rennet* (*e*).

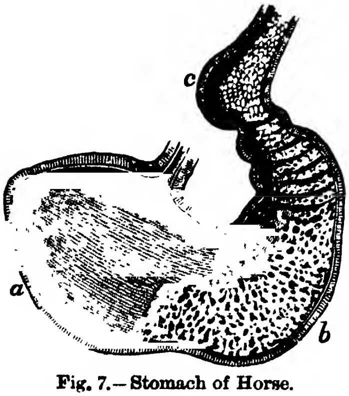

Fig. 7.—Stomach of Horse.
a, Cardiac Region of Stomach; b, Peptic Region; c, Pylorus.

Now it is a remarkable fact, on which, however, we have no space to dilate as we might, that in the horse, which is a close zoological ally of the cow, the inner wall of the stomach can be easily seen (Fig. 7) to consist of two distinct regions, one of which alone possesses the secreting cells; and, yet more—to use the words of Chauveau—"it is not by an insensible but a sudden transition that the mucous membrane of the stomach is thus divided into two portions; and their separation is indicated by a salient, more or less sinuous, and sharply-marked ridge." Merely mentioning that in the Camels, similarly hoofed animals, the paunch becomes fitted to be a store-house for a large quantity of water, and thus enables its possessors to traverse long tracts of arid desert; and leaving out of all present consideration every other form of stomach, we must, before leaving this part of our subject, direct especial attention to the arrangements which obtain in the blood-sucking Bat (*Desmodus*); for what we shall see in this animal will throw some light on the real significance of the digestive processes. Here we find, or rather here Prof. Huxley has shown us, that the cardiac portion of the stomach is very large, and that the pyloric region—or that in which the peptic glands are chiefly developed—is exceedingly small; to find the reason for this, we have only to look to the diffusible nature of the substance which forms the chief, if not the only, means of nutrition for these Vampires.

When we pass through the *pylorus*, or gate of the stomach, we come upon the intestine; this is broadly divided into two portions, *small* and *large*, which are in man and many of his allies distinctly separated from one another by the formation, at their point of junction, of a blind sac or cæcum; the small intestine is coiled upon itself and is made up of three regions, which are best, though not very definitely, distinguished from one another by the characters of their mucous membrane; these three parts are called respectively the *duodenum* (because it is about the length of twelve human finger-breadths), the *jejunum* (because it is generally empty after death), and the *ileum* (or coiled portion); the large intestine is *colic* or *rectal*, and the colon is (1) ascending, (2) transverse, (3) descending. Into the minute structure of these parts, their muscular bands or their connecting mesentery, our space is now far too short to enable us to enter; but a word must be said about the cæcum, not only because it is an admirable instance (in man) of what is known as a rudimentary organ, but because it affords us an example of the fact that similar contrivances have been resorted to in very widely-separated forms, and presses on us the important lesson that our laws are not always Nature's laws, and that that danger is a real one against which Wordsworth warned us, when he spoke of

> "That process by which we multiply distinctions,
> Then deem that our puny boundaries are things that we
> perceive,
> And not that we have made."

These are, indeed, weighty words to bring to bear on such a little subject as the narrow and somewhat short appendix to the cæcum which has got the name of *vermiform;* but it will be well if only we are reminded that nearly every natural fact, comparatively treated, affords an instructive lesson in disciplining the human mind.

These, then, are the facts: the wide cæcum suddenly diminishes very considerably in breadth, and forms a "vermiform appendix"; this is always found in man, and, curiously enough, in all the four forms of the man-like apes; here is obviously a grand opportunity for a broad generalisation, inasmuch as no other ape has such an appendix, and it is one which has, doubtless, been insisted on by some writers. The value of the character is, nevertheless, diminished by the fact, now quite well known to all zoologists, that a very similar vermiform appendix is also to be found in the Wombat, which is very far from being a close zoological ally to man, inasmuch as it belongs to that distinct group of the mammals which are known as marsupials (the kangaroo, &c.).

This fact has been insisted upon in this detail, for the purpose of expressly directing attention to the fact that similarities in arrangements are not always, or of themselves, to be taken as the sole mark of zoological affinity; community of ancestry, not similarity in adaptation to very similar requirements, must be always the test of real affinities.

Our limits here prevent us from entering into any account of the liver or of the pancreas, from both of which many instructive lessons in the processes of secretion might well be learnt. Even as it is, we have seen enough to show us that a careful study of even the most obvious parts of our own digestive system may easily lead us to get some glimpse into the wider laws which form the connecting bands between the innumerable details of Human Anatomy.

A PIECE OF PARAFFIN.

By John Hunter, F.R.P.S. etc.

We have here before us three specimens. One looks like a piece of the finest white wax, and is labelled paraffin; the second is a dull black piece of slate, or a slaty substance; while the third is liquid, and from its familiar odour seems to be petroleum. These three specimens, in spite of their apparent differences, are nevertheless close allies—indeed, two of them may be described as the raw materials of the other, which in some respects is one of the most important substances in nature. Its history, its discovery, and the chemical principles involved in its mode of extraction supply a useful lesson in many of the applications of modern chemistry, and, moreover, teach us much regarding the nature of the all-pervading carbon of which it is one of the many Protean forms. First, then, let us see what "paraffin" is.

As its name indicates,* it is a substance which exhibits, chemically, remarkable indifference to other bodies: that is to say, for example, vitriol and iron oxide when mixed form an entirely new substance—sulphate of iron, which of course is crystalline, and dissolves easily in water, and is popularly known as copperas or green vitriol, whereas when vitriol and paraffin are brought together there is no such change, there is no chemical combination. The vitriol and iron oxide have formed something quite different from themselves, viz., a beautiful green-coloured crystal, the constituents of which can no longer be mechanically separated, while the vitriol and paraffin remain vitriol and paraffin, and can be separated by simply pouring the one from the other.

Paraffin, which in a state of purity is of a beautifully white waxen appearance, can be obtained by the destructive distillation† of such materials as peat or coal, and also from petroleum or rock oil, &c., but it is mainly derived—and that as we will hereinafter show, in enormous quantities—from *shale.* The origin of these shale deposits and of other paraffin-yielding formations becomes therefore the first point for remark, and we cannot better introduce this part of our subject to the reader than by saying that the origin of shales and other oil-yielding strata is a question that has been greatly discussed; and of the many theories propounded regarding their formation, possibly there are none of them but can be taken exception to. Be that as it may, where such uncertainty obtains we need not rush into wild speculation, but shall content ourselves with making a few general remarks upon this head in addition to those already published.* These will be mainly to demonstrate the great antiquity of oil-yielding shales.

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* Latin, *parum,* little; and *affinis,* akin.

† Distillation consists essentially in converting a liquid into vapour by heating it in a close vessel, and then conveying the vapour into a cool vessel, where it is condensed again into liquid. "Destructive distillation" is the term applied to the process by which mineral, vegetable, and animal substances are heated in closed vessels of the nature of "retorts," at a temperature sufficiently high to decompose the original substance, and "obtain therefrom products possessing different properties from the material which yielded them."

The term *shale*† was at one period applied to all rocks splitting into thin layers—no matter what was their composition—occurring in what the old writers classified as Secondary and Tertiary formations. To the rocks, again, of the primitive formations that were of this thin splitting character the affix *schist* was employed: hence the origin of such compound words as mica-schist, talc-schist, &c., a method of description that is still in use. Shales, however, may pass through many modifications, and lose their schistose, or splitting properties. It may also be added that considerable liberties have been taken with geological terms, and thus we have some shales so named as to indicate little else than the part they play in commerce.

That the oil shales are of vegetable or animal origin—sometimes of the former, sometimes of the latter, and at other times of both—seems to be beyond dispute, if Palæontology is to be relied on. Paraffin-yielding substances—and by that we mean coal, petroleum, shales, &c.—are found in geological formations of every period, from Tertiary down to Lower Silurian, and by far the most important oil-wells in the United States are in Devonian and Silurian rocks. In the petroleum districts the products from decomposed and decomposing vegetable matter—we may almost with certainty say from ancient, and in some cases submerged, forests—filter continuously and slowly through the underlying porous strata, finding their way into wells from which the oil is drawn, while at other times, upon tapping the rock, the petroleum flows rapidly out, indicating in both cases the changes that are going on, which are none other than Nature herself performing majestically and surely what vast sums of money and thousands of our fellow-men are in this country employed daily in doing. That these formations, then, are the outcome of vegetable and animal matter that has undergone, and is still undergoing, extraordinary chemical changes, and that they have been subjected to both enormous heat and pressure through vast periods of time, seems to be without a doubt.

To say that the ancients were unacquainted with petroleum and paraffin oils, or even with the solid paraffin itself, would be venturing a statement that in all probability is not correct, for certain it is that they were quite familiar with bitumen, naphtha, &c.—in fact, with mineral oils which Mother Earth has for centuries been vomiting forth unaided and unchecked.

In the year 1761 black bituminous shale was employed for the production of oils which were used for the cure of certain diseases, but perhaps the earliest trustworthy record we have of what in all probability was the distillation of coal or shale is 1694, in which year patents were granted "for the production of pitch, tar, and oyle out of a kind of stone." Whether it was that animal oils were more plentiful at this period, or that at any rate they were sufficient in proportion to the population, is a question which statisticians hesitate in answering, but it is not difficult to observe that as the population went on increasing enormously, the importation and home production of animal oils was not carried on in anything like a proportional ratio. It is, therefore, not to be wondered at that many scientific and practical men followed in the wake of these early discoverers, and that between the year 1781 and the present time not fewer than 200 patents have seen light, these patents being mainly for improved stills or retorts, or for some modification of processes for manipulating paraffin-yielding substances, such as shale, whereby a greater proportion of marketable products are obtained, or, as is the case in using a low instead of a high temperature, the products from the distillation are of a more valuable nature. One of the most intelligent of the observers towards the close of the eighteenth century was the Earl of Dundonald. That nobleman, we are told, amused and amazed his audiences in the year 1786 by distilling coal or shale, and passing the incondensible gases to the end of his lecture-table, where the gas was burned.

Dundonald had, however, been working for some years previously, and very systematically too, for we know of his having produced in 1781 oils by the destructive distillation of a kind of coal; and, to his credit be it said, these operations were carried on in ovens in many—if not in most—respects similar to those in use until a very few years ago, and not widely different from those still employed.

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* "Science for All," Vol. I., p. 342.

† German, *schälen*, to peel or shell off.

About the same period, 1781, other *savans* were in the field, who contributed not a little to our knowledge of products of distillation, among the foremost of the workers being Laurent, Reichenbach, and Gillespie; and perhaps it was due more to those men than to any others that the paraffin industry became a reality, for as a result of their labours tars and oils became marketable articles, and extensively used both as lubricants and illuminants.

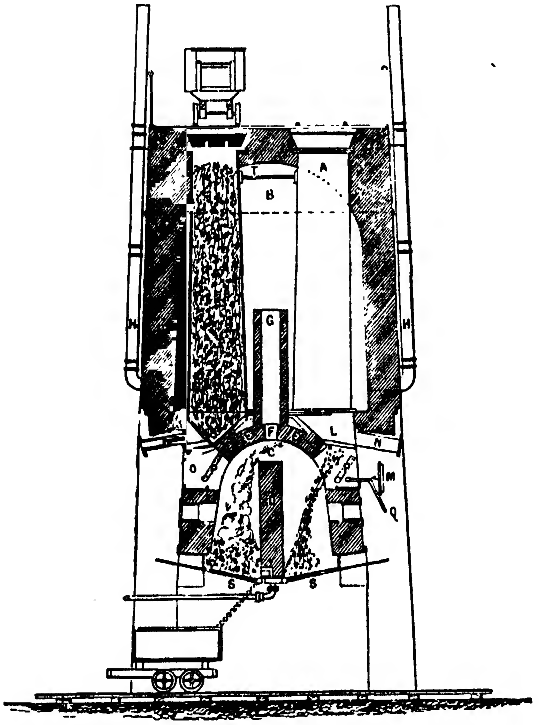

Fig. 1.—Cross Vertical Section of the Henderson Retort.

As has already been stated, during the century that has passed—since 1781—patents were rolled out more rapidly than the years rolled on, but it was not perhaps until the 7th day of October, 1850, that the foundation was laid of what is now, and promises more and more to be, one of the most important industries in this and other countries. On this date letters patent were granted to James Young, then of Manchester, for the "obtaining of paraffin oil, or an oil containing *paraffine*, and paraffin from bituminous coals." Evidence is not wanting to prove that this was the foundation of the paraffin industry, or that it was at least one of the turning points in its whole history.

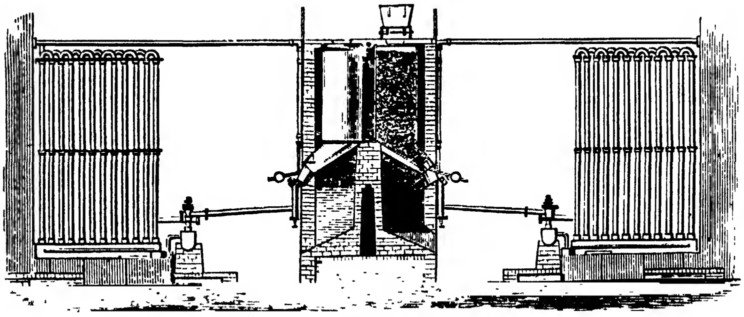

Fig. 2.—Young's Retort (Partial Section, and partial elevation).

The material upon which Mr. Young first worked was the once famous but now practically exhausted Torbane Hill mineral, a substance which was the subject of tedious and costly litigation between the proprietor of the so-called *coal-fields* and his lessees. The point which was tried to be settled was whether this Torbane Hill mineral was a *coal* or something else, and in spite of the many chemists and geologists engaged on one side or another the result was a compromise. It is, however, now little doubted that the Torbane Hill mineral was not a coal, but that it was a true and a remarkably pure shale.

Paraffin is now obtained to a great extent from the argillo- or calcareo-bituminous shales which are girt by the sub-carboniferous or Burdiehouse limestone formation. These are more commonly known as the oil shales, and extend throughout the counties of Edinburgh, Linlithgowshire, Lanark, Fife, Ayr, and Renfrew.

But a few years ago the chief products from the distillation of shale were the light and heavy, or burning and lubricating oils; the importation of enormous quantities of American petroleum, however, so reduced the market value of paraffin oils that necessity again asserted and maintained her maternal dictum, with the result that a number of patents have been granted for improvements in processes and apparatus whereby products of destructive distillation of shale are obtained which are of so much greater value that, whereas only a few years ago paraffin-oil works were being carried on at a loss—or, at best, only paying working expenses—now the tables are so completely turned that the production of paraffin is highly profitable.

We have thus seen that paraffin is derived from the destructive distillation of shale. This operation, which was wont to be carried on in fire-clay ovens or retorts, such as are used in gas works, is now in Scotland almost universally conducted in cast-iron vertical retorts, as represented in Figs. 1 and 2. Fig. 1 is known as the Henderson Retort, and Fig. 2 is the retort, &c., of Mr. Young, late of Straiton, now of Clippens.

In the Henderson retort, A, the oven, B, is constructed in brickwork in much the usual way, and there is formed in the lower part of the building a large fire chamber or fuel space, C, which is divided across its lower part by a partition, D, which may be of brick, but which preferably consists of an iron casing formed with serpentine or tortuous internal passages for the conveying and superheating of gas or steam, which is introduced at the top of the retort by pipe T.

The fire chamber, C, is surmounted by an arched roof, E, along the centre of which apertures, F, are formed for the passage of the fire gases into the oven space, B, above. The fire gases are led at first towards the upper part of the oven, B, by vertical flue walls or screens, G, and they finally pass off from the oven by chimney, H, leading from the outer bottom parts thereof. The bottom of each retort, A, is formed with its inner side bevelled, and it is built into and projects down through the sole or floor, K, of the oven, B. The discharge opening, L, of the retort is formed at the extreme bottom end, and it and the cover, M, are slightly inclined from the horizontal, the lower end being outermost, so that oil falling on the cover may run down it towards the oil outlet, N.

The oil outlet, N, is covered by a grating to prevent the entrance into it of the shale or mineral. The retort bottom, L, is situated in a casement or space, O, made with an iron framing fixed in the building, and with its inner end opening into the fire chamber, C, whilst it is also open on its outer side. In the casement, O, there is an inclined valve, P, consisting of an iron frame, lined or fitted with fire-clay, and arranged to turn on journals at its bottom corners. This valve, when in the position in which it is shown in Fig. 1, separates the bottom, L, of the retort from the central fire chamber, C, and thus completely prevents the fire from injuring the cover or door, M, and its fittings. When, however, the cover, M, is removed, the valve, P, can be turned over into the position in which it is shown at the right-hand side of Fig. 1, and it then forms an inclined plane or shoot to guide down the spent shale from the retort, A, into the fire chamber, C. The cover is made tight with a suitable luting, such as a mixture of lime and clay; a lever works in bearings at the bottom of the casement, Q, so as to remove cover, M, away from the retort. In order to fix the cover, M, tightly when in position, a wedge is driven in at each side of the casement. Within the bottom of the retort there is a grating, R, keeping up the shale or mineral until it is to be discharged, and this grating is hinged at its upper corners to snags cast inside the retort, whilst it is held up in a position by a strut hinged to one side of it, and which is drawn away outwards by means of a hook after the door, M, has been removed and the valve, P, turned over outwards to allow the spent shale or mineral to be discharged from the retort, and to descend into the fire chamber, C. The bottom of the fire chamber, C, is provided with a movable bottom, S, which is hinged at the back, and wrought by a counterpoise weight at the front, which admits of the easy removal of the ashes or exhausted earthy matter into wagons below.

The old process employed consisted in charging the retort with shale and applying heat to the *bottom* of the retort by burning coal. So soon as all that was volatilisable was expelled from the retort, the fire was "drawn," and the "spent shale," or residue after distillation, put into iron trucks, which were emptied at some convenient spot close by, the result being the accumulation of huge "bings" of smouldering material so familiar to every visitor to these oil-works.

Now, however, the lately so-called *spent shale*, which contains a considerable proportion of carbon, is allowed to drop by the openings L and P (Fig. 1) into the fire-place, C, where it mixes with atmospheric air, and also with the incondensible gases passing into the heating chamber, C, by the apertures F, and by these aids—air and gas—the carbon in the spent shale is burned. Thus the process is now a continuous one, little fuel being used save what until recently were almost entirely waste products. In fact, whereas a *new* fire of coal or other heat-producing material was necessary for every charge of a few hundredweights of shale, now, once started, the process is practically an endless one, and but for the fact that it is advisable to clear out the passages—for the products of the distillation—each week, it might be looked upon as so far a "perpetual" one that it can go on just as long as the retort will last, but little extraneous fuel being required, save what is necessary for the first kindling.

Briefly described, the whole process for the production of paraffin is as follows:—

The shale, on being "mined," is placed in cages and raised to the surface, where it is emptied into a machine that breaks it into pieces of a convenient size; from this breaker it drops into trucks or hutches, and by an ingeniously applied endless rope the trucks are pulled to and from the retorts into which they are emptied, without the shale being handled since leaving the pit bottom. The products from the first distillation are spent shale—used as fuel to heat the next charge—ammonia water, and crude oil. The ammonia water, when boiled, yields its ammonia as a vapour, which is passed into sulphuric acid, and forms sulphate of ammonia, used mainly for agricultural purposes. The crude oil passes on to the refinery, where it is distilled to dryness, the products being coke and green oil. The green oil is treated alternately with sulphuric acid and caustic soda solution, each of these treatments yielding a black tar, which sinks to the bottom of the tank, leaving the oil on the top.

Green oil is again distilled, and yields light—or burning—oil, and heavy oil and paraffin. The *light* oil, if not now sufficiently free from colour and odour after treatment with sulphuric acid and caustic soda, is again distilled until pure enough to send to market. *Cold,* if we may so express it, is conveyed from a freezing machine to the mixed heavy oil and paraffin, the resulting low temperature causing the paraffin to crystallise, so that when the mixture is put into the press (Fig. 3), by opening A, the oil is expelled at from B to C, leaving behind the solid paraffin.

Necessarily we have omitted a great amount of detail of the process, such as production of naphtha, "still grease," employment of steam at some of the distillations, &c. Suffice it to say nothing need be lost in a properly conducted work. Spare steam can always be used up; the *tars* can be profitably employed, either by mixing the acid and soda tars and heating them by waste steam, the products on cooling being—1st, *tar*, to be used as fuel, and 2ndly, sulphate of soda, a salt of some commercial value; or the acid tar alone similarly treated will yield—1st, tar, and 2ndly, sulphuric acid, to be employed for absorbing ammonia at the first operation, the distillation of the shale. In these two operations, after cooling, the tar separates almost perfectly, in the first case, from the soda sulphate, and in the second from the sulphuric acid, which is run off by a stopcock at the bottom of the settling tank, leaving the supernatant layer of tar behind.

What, then, are the properties of the chief substance left behind? Paraffin (of which Reichenbach is said to have been the discoverer) we have seen is a wax-like, white or colourless crystalline substance, and it is both inodorous and tasteless. It possesses none of the staining properties of oil, and in that respect leaves no impression upon paper, which therefore may be employed for protecting paraffin specimens from dust, &c. The *melting point* of paraffin varies to some extent, these variations being probably due, in some measure at least, to the temperature employed in the distillation, as well as to the source from which the paraffin has been obtained, but it is generally stated as being from 110° to 114° Fahr., and it has a specific gravity of 0·870. When brought to the boiling point it gives off white fumes, and when it is ignited it burns with a beautifully clear white light, and leaves no residue or ash. When subjected to dry distillation it undergoes no change, *i.e.*, it is not decomposed, neither is it affected by the strongest acids or alkalies, but it is miscible by fusion with such substances as resin, phosphorus, sulphur, and wax, and it is in this last combination—namely with wax—that paraffin is employed for candle-making, for the reason that the mixture does not melt so easily,—in fact, has a higher melting-point than paraffin alone, the candles so made being consequently much more durable. Paraffin may also be used in lamps for illuminating purposes when it is dissolved in hydro-carbon oils, and in this combination it emits a brilliant white light; but the drawback is that the paraffin is liable to separate from the oils in cold weather, and therefore will not ascend the wick. It dissolves easily in ether and in essential oils, and the softer description of paraffin, when dissolved in naphtha and mixed with about one-twentieth of its weight of vegetable oils, forms a material that is excellently suited for waterproofing cloth, linen, india-rubber hose, leather, and so on, these fabrics, &c., besides being rendered waterproof, having their tensile strength very greatly increased. Paraffin is also largely used for preventing decomposition of preserved and natural fruits alike, and it has also been somewhat successfully used for coating imported butcher's meat. In lucifer-match-making also, paraffin has done good service, for these articles of commodity, when the wood has been treated with melted paraffin, ignite easily, and burn without producing any such disagreeable odour as is the case with sulphur matches. Brewers, again, have resorted to the use of paraffin for coating barrels, the object being to prevent beer which has "soured," or is undergoing any other fermentative process, from so affecting the wood as to impart contamination to future contents of the cask. Spinners and weavers likewise have of late years employed paraffin to a considerable extent in the manufacture of yarn and cloth. Cork, which is very porous, may be rendered comparatively impervious to air by sinking it in a vessel containing melted paraffin, placing that under an air-pump receiver, and exhausting the air. Immediately air is again allowed to enter the receiver—which must, of course, be done while the paraffin is still liquid—the paraffin is forced into every pore of the cork, which thus becomes, as we have said, practically impervious. Paraffin is put to many other uses, among those being its employment as an "insulator," and for this purpose it is undoubtedly one of the best substances at the command of electricians, probably on account of its freedom from, and non-liability to absorb, water.

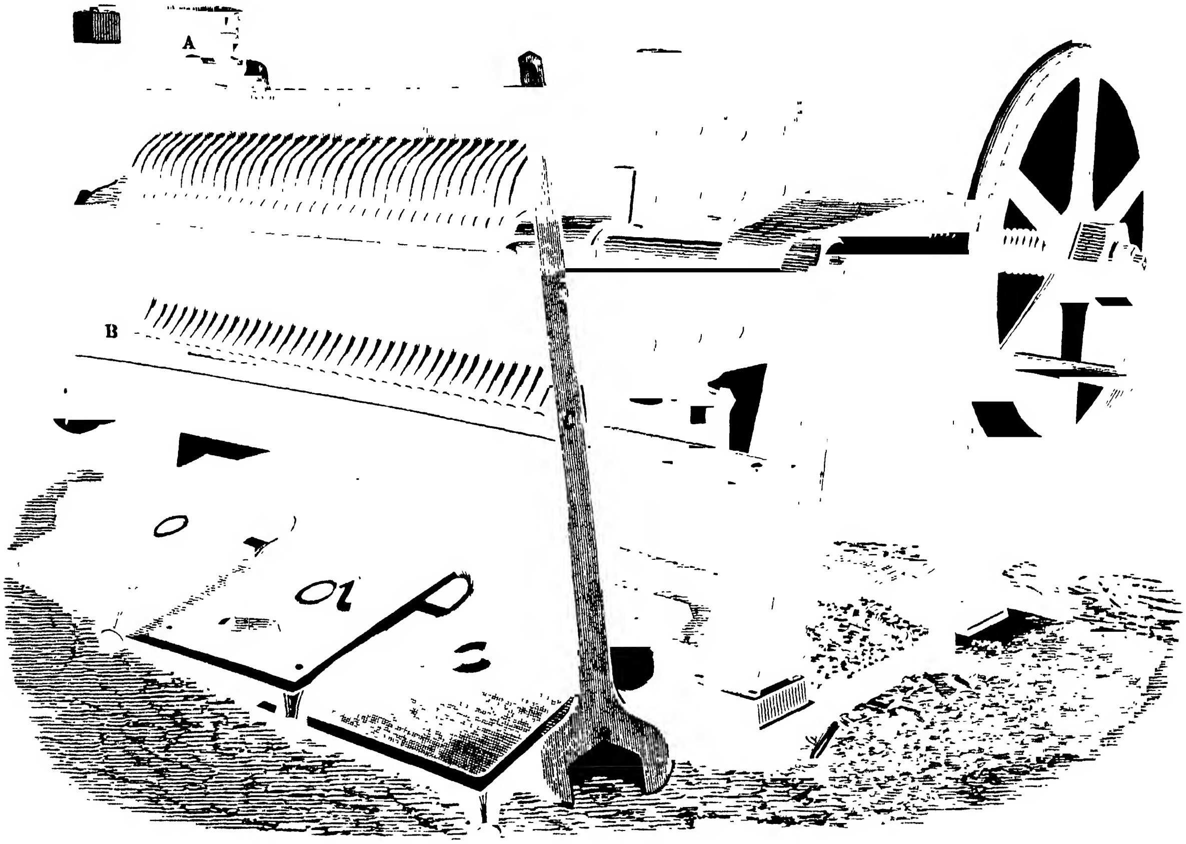

Fig. 3.—Paraffin Filter Press.

In medicine or surgery possibly the only use to which shale paraffin is put is in the dressing of wounds, but there is a substance which is obtained by boiling petroleum and repeatedly filtering it through animal charcoal—a similar process to that employed for separating sugar from organic and other impurities—that has come to be almost universally used by druggists. This material, which we may be allowed to view as petroleum paraffin, and which is now known in medicine as "vaseline," is rapidly displacing the employment of lard, &c. in the preparation of medical ointments, because of its paraffin-like properties of being tasteless and inodorous, and of its non-liability to become rancid.

Some idea of the importance of the paraffin industry may be gathered from the following table, which is an approximate, and probably very accurate, estimate of its position in 1880 :—

	In Scotland alone the capital employed is	£1,300,000
Estimated Produce for the year 1880	Shale distilled	800,000 tons
	Coal used in manufacture ...	350,000
	Sulphate of ammonia produced	4,200 ,,
	Naphtha produced	1,300,000 gallons
	Burning oil produced ...	10,400,000 ,,
	Lubricating oils ,, ...	3,900,000 ,,
	Crude paraffin ,, ...	7,500 tons
	Refined paraffin ,, ...	5,000 ,,

This refined *paraffin*, which is used in candle-making, reckoning that every pound of paraffin gives fifteen candles, is capable of producing the enormous number of 168,000,000 candles.

In refining the above-named products there are required :—

Sulphuric acid	10,600 tons
Caustic soda (60°/o)	1,200 „

Viewed chemically, the paraffins are a series of compounds of carbon and hydrogen, and are called *saturated hydro-carbons*, because the number of atoms of hydrogen exist in the fullest proportion in which these two elements—carbon and hydrogen—can combine, and furthermore the hydrocarbons of this series cannot combine directly with any other element. Thus, before chlorine can form a part of a molecule of one of those hydro-carbons, an atom of hydrogen must first be *removed.* The lowest of the series—marsh gas—has the composition CH_4 (that is, one atom of carbon and four of hydrogen); the second—or ethane—has two atoms of carbon and six of hydrogen (C_2H_6), then follows propane (C_3H_8), each succeeding member being obtained by one additional atom of carbon and two of hydrogen. The solid paraffin, which has been the subject of this paper, is probably a *mixture* of several members of this series of "saturated hydro-carbons."

That the present method of manipulating shale will ere long undergo considerable change seems more than probable, for at this moment attempts are being made to supplement the production of ammonia (which is a compound of hydrogen and nitrogen) by so constructing the retorts that nitrogen may be absorbed or taken from the air. If such a process be perfected and set in operation, and if the present composition of the air be necessary for the existence of man *as he is*, then it may follow that destroying the balance of what we require to breathe may proportionately modify species. But whether that modification will be in the direction of degradation, improvement, or "in improving off the face of the earth," it is needless speculating. Unnumbered ages ago the materials of light were entombed in the clays of the earth, there to remain until man required them. It will be a stranger revolution still should man, in his greed or his necessities, deprive his race of the air necessary for his being, in order to obtain the light and comfort which are stored up in the rocks for his use!

FOGS.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.

SIXTY years ago, and immediately before he was placed in the distinguished position of President of the Royal Society, Sir Humphry Davy occupied himself, whilst travelling upon the Continent, with some interesting observations relating to the atmospheric conditions that are connected with the production of mist and fog, and he shortly afterwards gave an account of the conclusions at which he had arrived in a paper which was printed in the "Philosophical Transactions" of 1819. In that communication he states that he noticed as he passed along the Danube, between Ratisbon and Vienna, mist appeared in the evening upon the river only when the water was from three to six degrees warmer than the air, and always disappeared in the morning as soon as the temperature of the air had risen above that of the water. On a certain evening in June, at a spot where the rivers Inn and Ilz flow into the Danube, when the temperature of the air was 54°, the water of the Danube was 62°, that of the Inn $56\frac{1}{2}$°, and that of the Ilz 56°, the whole surface of the Danube was covered with a thick fog, the Inn had only a slight mist over it, and the air above the Ilz was quite clear. On the following evening the temperature of the air was 63°, and higher than that of the water, and no fog was visible anywhere up to the time of the last gleam of the fading twilight. Perfectly similar results were met with on the Rhine, Save, Isonzo, Po, and Tiber, and on the small lakes upon the Campagna, near Rome. Mist never appeared when the temperature of the air was higher than that of the river. These early observations of Davy left no doubt as to one important cause of the formation of mist in the valleys of rivers. The comparatively warm water steams its vapour up into the superincumbent air until this is charged with as large an amount as it can contain in an invisible state. But the full saturation of the air does not put a stop to the yet further rise of vapour. Evaporation still goes on, and the surplus of the vapour forthwith appears in the visible form of aqueous vesicles. The colder the air in reference to the water the sooner the point of aqueous precipitation is reached. If there is a briskly moving wind, the mist may be drifted away pretty nearly as rapidly as it is formed; but if the air is comparatively still, the gathering mist deepens and spreads far beyond the position in which it is primarily generated by the action of condensation, and hangs over the valley until the conditions of the atmosphere and water are changed. White mist may often be seen in process of transport by very gentle currents of air from the places where it is formed. Mr. Dines, a meteorologist who has given close attention to what may be termed the dynamics of mist, on one memorable occasion saw white haze advancing steadily through a gap in a hedge near Cobham, and crossing a road to get under the shelter of a neighbouring wood.

It is quite easy to understand, under the suggestion of these direct observations by Sir Humphry Davy, why it is that night mists so commonly hang over the surface of large rivers until they are dispersed by the beams of the rising sun. The cooling of a considerable body of water necessarily takes a longer time than the cooling of a corresponding area of solid ground. The cooling of the ground is restricted to a very moderate depth, because the heat from below does not travel up to the actual surface as readily as it is radiated off from that surface into the air. But whenever the immediate surface of any considerable collection of water has been reduced to a temperature of about 45°, that portion of the liquid grows heavy and sinks, and warmer water from below rises up to take its place. On this account the surface of water cannot become the coolest part of the mass until the whole has been chilled to something like 40°. Water, therefore, which has acquired about the same temperature as the neighbouring land by day generally remains warmer after sunset and through the night. Its comparatively high temperature is sustained by the store of heat which is being continually brought up towards the surface from the greater depths. The air above the land thus habitually becomes cooler at night than that above the water. The air is kept warm by the water and cooled by the land. If therefore, in both situations it contains the same inherent amount of aqueous vapour, some portion of this is precipitated as mist whenever the cold air of the land is mixed with the warm air of the water, and the precipitation is the more abundant in proportion as the surrounding land is higher, the water deeper, and its temperature greater. Mist occasionally forms over grass when adjoining bare ground is clear, simply because the rapid radiation of heat from the grass more speedily brings the superjacent air to a temperature low enough to produce the condensation of its vapour. When newly-ploughed ground becomes covered with mist whilst the neighbouring pastures remain clear, that is due to the circumstance that the freshly turned-up soil is warmer than the grass, and in a state more favourable to the copious emission of its moisture as vapour. The effective cause of the production of mist is the sudden chilling of warm moist air. But it is quite immaterial how this is brought about; it is of no consequence whether the chill is applied from above or from below. In the case of a broad and gently flowing river, such as the Thames, the chilling influence most commonly acts from above; but it is quite possible, even with a running stream, that matters may be reversed. Sir John Herschel has drawn attention to the circumstance that cold mountain streams cover themselves with mist as soon as they reach low and comparatively warm levels of the atmosphere. In such instances they carry in themselves the cold which is essential for the condensation of the vapour, and the mist appears because the air is warmer than the water.

Still, as well as cold, air is requisite for any dense accumulation of mist, because moving air, even when it is cold, may serve to sweep away vapour as rapidly as it is thrown down. It is on this account that mists are so prevalent in low and sheltered situations. It is no unusual thing to find the wind-swept open reaches of rivers covered with clear air when mist is hanging thick upon more sheltered parts. Sir Humphry Davy observed upon one occasion that the surface of the Danube remained clear at night, although the water had a temperature of 61°, when that of the air was only 54°; but this happened when a strong and dry easterly wind was blowing upon the river. Brisk movement of the air is also unfavourable to the production of mist for another reason: it tends to equalise the temperature at contiguous places, and so to prevent the sudden commingling of hot and cold masses of air.

A mist is thus, in reality, a shallow cloud resting in contact with the surface of moist ground or of water, and formed by the influence of cold, either brought by a current of water or wind, or caused by the action of radiation. Fog differs from mist only in the circumstance that it is of larger extent and greater depth. It is mist accumulated until it is of more considerable dimensions. The word fog is apparently derived from the old Anglo-

Saxon term which signified to "collect" or "gather."*

The London fog, which is so unpleasant a characteristic of the great city during a considerable portion of the season of winter, is unquestionably connected with the circumstance that this vast metropolis stands in the broad valley of the Thames. The water of the river remains comparatively warm when the superjacent air has been considerably reduced in temperature, and consequently the vapour which steams out from the warm water is chilled almost immediately into mist. If there is a brisk movement of the wind across the river the mist may be swept away as rapidly as it formed; but if the air is approximately still the mist gradually gathers over the river, and spreads up the sloping sides of the valley. The windings of the stream have been seen from a balloon floating at a great elevation above, traced out for a considerable distance by an unbroken sinuous line of fog. With a gentle wind sweeping transversely to the general direction of the stream, the fog drifts slowly along from the spot where it is formed, and it is on this account that it is so often prevalent in one district of London when no trace of it appears on the opposite side of the metropolis. With a north wind the fog haunts the southern banks of the river and the southern slopes of the valley; with a south wind it only rests on the north side of the river. On the afternoon of the 18th of October, 1877, Mr. Whipple, the superintendent of the observatory at Kew, saw a low dense sheet of mist, half a mile wide, move across the Richmond Park in what seemed to be at the time an absolute calm. The air was so perfectly still that the smoke was ascending as a perpendicular column. The lower surface of the mist was about twenty feet above the ground, and the whole mass drifted steadily along from the north-east over Richmond. It was observed just at the same time that the smoke of the chimneys at Kingston rose perpendicularly for a considerable distance into the air, and then spread itself out into a horizontal sheet. The fog-drift in the Richmond Park was most probably due to an upper current of wind moving gently along over an undisturbed layer of the atmosphere beneath. Mr. Dines holds that mists are often formed in consequence of the entire body of the air being suddenly chilled to a considerable distance above the ground by some unascertained physical agency, and urges that this probability must not be lost sight of in our investigation of the natural history of fog.

But that peculiar form of mist which is unhappily known as London fog is something more than water condensed in moist air by the influence of chill. In the dense white mist of the open valleys large objects, like the level top of a wall, can be seen by daylight through the obscured air as far as two hundred yards away. In a genuine London fog the same object would not be visible at a distance of two yards. In such circumstances the bright flame of the gas-lamp entirely disappears at night at a distance of sixty paces, or from 120 to 150 feet. In the November fog of the metropolitan streets the gas-lamps are not visible from each other. Each light only glimmers into sight after the advancing pedestrian has passed the adjoining lamp-post, and plunged some distance forward into the gloom. This dense obscurity of the London fog is due to the fact that it consists of smoke as well as mist. The smoke, which is the ordinary product of the imperfect combustion of coal, gas, and other compounds of hydrogen and carbon in the thickly-peopled city, gets arrested for a time in some form of entanglement with the mist, and accumulates with it until the compound becomes more or less impervious to the vibrations of light.

That carbon is habitually deposited in the smoke laden air over London in a very substantial form, and in very considerable quantity, is only too obvious in the shower of black flakes that so continuously falls, and that so pertinaciously and obtrusively penetrates wherever any crevice is left open for its reception. The smoke which pours out into the air from the chimney-tops is all carbon in an unconsumed state. It is charcoal disintegrated into the condition of a loose flocculent powder by the action of fire, and then drifted away upon the currents of heated air which are driven up the flues. It has been ascertained that as much as nine per cent. of the fuel that is devoted to the maintenance of artificial fires in London escapes unconsumed up the chimneys as smoke. Under ordinary circumstances these unconsumed fragments of the black charcoal are carried at once away by the wind to be deposited far and wide upon the ground. But when the air is still and laden with mist, the black substance is suspended with the mist, and so hangs as a murky canopy over the town. The black particles which are carried up into the air very rapidly radiate, or throw off their heat, as all rough and dark bodies do, and there is then a coating of moisture deposited round them from the damp air as soon as they are cold enough to produce a condensation of the vapour. In air fully saturated with moisture this goes on until each chilled floccule of carbon has its own aqueous film surrounding it as an investment. The gathering mist is then composed of white vesicles of water, containing dark carbonaceous kernels within; the mist-spherules are moulded upon central granules of charcoal. But simultaneously with, or in addition to, this there is another form in which carbonaceous substance is in all probability connected with the mist-spherules in London fog, to which Dr. Frankland, Professor of Chemistry in the School of Mines, has been the first to draw pointed attention.*

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* Fegan—to collect or gather.

Dr. Frankland was led to the conclusions at which he has arrived in this matter by observing that the dark London fog is often "*a dry fog*"—that is to say, that it not unfrequently occurs when the air is far from being itself saturated with moisture. On the 17th of October, in the year 1878, at a time when a dense black fog was hanging over London, observations with proper meteorological instruments showed that the humidity was only 80 per cent.—or, in other words, that the air still had a capacity for receiving as much as a fifth part more aqueous vapour before it was so saturated that the deposition of visible mist must ensue. Upon following up the suggestion which was presented in this way, and extending his inquiry to other instances of dark fog, it soon appeared that this was by no means an unusual circumstance, and that the dryness of the fog was far from being an exceptional occurrence. In eighteen fogs concerning which he was able to get exact scientific information the humidity ranged between 50° and 87°, and in no one case did it approach to saturation. This, of course, could only mean that the clear intervals of air intervening between the aqueous spherules of the mist were comparatively dry, or in other words, that the condensed moisture which was unquestionably present in those mist-spherules was so shut up in them that it could not produce its natural effect in moistening also the circumambient air. The question therefore quite naturally occurred whether the opaque light-intercepting or carbonaceous ingredient of the fog might not be the cause of this shutting up, or insulation of the deposited moisture, and it was to the determination of this question that Professor Frankland proceeded to apply the test of experiment.

He first placed two shallow platinum dishes of exactly the same size, and containing the same quantity of water, side by side in a draught of air, and he then poured a thin film of coal-tar over the surface of the water in one of the dishes. After twenty-four hours he found that the unprotected water had lost 111 grains by evaporation, but that the water covered by the coal-tar had lost only seventeen grains. In another experiment, in order to approach still more nearly to the exact condition that prevails in smoke-laden air, the smoke from burning coals was blown for some time over the surface of the water in one of the dishes, instead of floating coal-tar upon it, and then after eighteen hours' exposure to the draught the uncovered water lost sixty-six grains by evaporation, and the smoke-protected water only fifteen grains. Other experiments of a similar character were made, in some of which the evaporation was produced under large bell-jars into air kept dry by concentrated sulphuric acid, instead of by an open draught, and in all a similar result was obtained. The tar-covered or smoke-protected water had its evaporation materially retarded. Dr. Frankland next proceeded to coat single drops of water, suspended in loops of platinum wire, with coal-tar and with deposits from coal smoke, and then left them for some hours exposed in dry air. In these instances he found it somewhat difficult to prevent the protecting films from running up the platinum wire from the drops. But he was nevertheless able to get results which left no doubt that drops covered in this way had their evaporation materially diminished. The covering films served to shut in and confine the moisture, and to prevent it from extending its influence to the surrounding air.

From these very beautiful and ingenious experiments, therefore, Dr. Frankland has been led to infer that the London fog is a dark fog, yellow or black, because the spherules of its mist are coated over with an opaque pigment of a volatile nature generated by the destructive distillation of coal, and conveyed to them by the smoke, and that it is a dry fog because the spherules of moisture are shut up within these coverings of varnish. The mist is incarcerated as rapidly as it is generated in little impervious bags, which are fabricated out of a product of the combustion of fuel that is volatile and easily diffused at high temperatures, but that ceases to be so when chilled down to the ordinary temperatures at which aqueous vapour is deposited in the outer air. It is these dark carbonaceous tar-like deposits that render the London fog so irritating to the sensitive membranes of the eyes, and of the nose and lungs, when it is breathed.

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* "Proceedings of the Royal Society," Vol. XXVIII., No. 192.

Fogs which have had their mist-spherules painted over in this way are obviously in the best possible condition for the interception of light. Every one is aware that a piece of well-smoked glass may readily be made so impervious to light that the full blaze of the noontide sun may be looked at through it without any other protection for the eye. All observers who have been in the habit of contemplating the sun through smoked glass will know that the appearance communicated to its luminous face is precisely similar to that which it assumes when it is looked at through a yellow London fog. In the case of the fog, the light which attempts to penetrate through the mass is stopped and turned back by the numerous opaque particles that stand in its path. As it makes its way on into the crowd of the thickly-serried molecules it is reflected from their impenetrable surfaces again and again, and some portion of it is absorbed and quenched with each reflection, until in the end no luminous impulse remains. In very dark fogs the obscurity sometimes approaches very nearly indeed to the absolute darkness of night. But this occurs only over large towns, where there is an ample supply of the smoke pigment for the coating of the mist-spherules.

In considering the nature of yellow town fogs it must not be altogether lost sight of that there is yet another source of contamination and impurity besides the coal-fires and gas-flames, which is continually yielding some additional contribution to the stagnant mass. In London, besides the larger fires, there are more than three millions and a half of slow furnaces pouring out their waste exhalations and vapours upon a miniature scale. It has been calculated that not less than 800 tons of charcoal are sent up into the air every day from the lungs of the living and breathing human inhabitants of London alone, without taking any account of the vast crowd of lower animals that are their associates and dependents. These are not seen, because, happily, these slow furnaces accomplish the task which the brisker and larger fires leave incomplete; they do consume their own smoke. They convert the exhaled carbon into an altogether transparent and invisible gas. But this invisible exhalation is all mingled in with the stagnating vapours that are collected in fog. That a considerable amount of moisture is contributed to the air from the lungs of human beings is plainly indicated in the cloud of mist which is seen to issue from the mouth at each expiration on a cold frosty day. Scarcely less than two million pints of water are furnished to the air over London every twenty-four hours from this source. This water contains a considerable amount of volatile exhalations, resulting from the chemical operations in progress within the living and breathing organisms, and all these are added to the ingredients arrested with the condensed moisture in time of fog.

Dense fogs are unfortunately, however, not confined to the valleys of rivers and to the neighbourhood of thickly-peopled towns. They occur upon the sea whenever the water of the ocean is warmer than the air that is resting or moving upon its surface, and this is especially apt to occur in the immediate vicinity of coasts, where a chill atmosphere is most apt to be rapidly generated at night. The fog in such situations is a very unwelcome and inconvenient incident, on account of the delay and danger it entails upon approaching ships, which cease in such circumstances to be able to avail themselves of visible landmarks scattered along the coast. The long list of accidents occurring to vessels in fogs sufficiently indicates the peril with which even the white sea-mists are attended.

The importance of an organised system of signals around frequented coasts which can be seen by night as well as by day is recognised by all civilised nations that have maritime frontiers. The coasts of Great Britain are studded at night by a belt of warning lights, which not only tell approaching mariners of the propinquity of land, but also in a language of their own inform them of the nature and position of that land, so that it can be identified upon the chart. It has been calculated that there is not less than a line of 9,392 miles of coast-line surrounding the British Islands. Upon a recent occasion when a careful survey was made it was found that at that period there was a lighthouse to every fourteen miles of coast in England, to every thirty-four miles in Ireland, and to every thirty-nine miles in Scotland. When the floating lights were added to the tale it appeared that there were lights, upon an average, within twelve miles of each other all round the sea-shore of England The first plan adopted for establishing night signals of this character upon the coasts consisted of the obvious device of lighting fires upon the projecting prominences of the shore; but soon it occurred that it was advantageous to build towers for the reception of these signal fires, because they then became visible at a greater distance out at sea. Wood or coal fires were then kindled in iron baskets, which were placed at the summit of the towers. The earliest fixed lighthouse of this character of which any trustworthy record remains is that which stood upon the island of Pharos, in the sea-approach to the harbour of Alexandria, and which was built by Ptolemy Philadelphus, two thousand three hundred and fifty years ago. It is said that the fire in this tower was visible forty-five miles away. There is the ruin of an old lighthouse near the castle at Dover of a similar kind, which is reputed to have been established during the Roman occupation of England. When the first Eddystone lighthouse was opened, in the year 1759, the fires of the earlier time had been superseded by candles. Oil-lamps were introduced in the place of candles by the French engineer Borda, between 1780 and 1790, with polished reflectors behind to increase the brilliance of the light. The improved system of Fresnel, in which transparent lenses and prisms of glass were placed in front of the lamps to collect the luminous rays, and to concentrate them into flashes which could be thrown in certain definite directions over the sea, was brought into operation in 1825. In the best arrangements of this system oil-lamps with four concentric burners are used, and many lamps are combined to constitute each light. The best lights of this class are so bright that they are capable of penetrating the darkness on a clear night for thirty miles, but in order that they may be seen from the sea at such a distance it would be necessary that they should be raised 594 feet into the air. The Eddystone lighthouse, which has been replaced by a new and loftier structure, has a light ninety feet high, and visible nine miles away. The generality of shore lights have lanterns from 110 to 220 feet high, and are visible at distances from fifteen to twenty miles; and this is held to be enough for all practical purposes of utility.

In most of the lighthouses of the present day a very much stronger light is, however, provided than is required on clear nights at the distances from which it can be seen. The reason for this is that a provision has in this way to be made for times when there is some haziness or obscuration in the air from fog. Arrangements are also made in the best appointed lighthouses to bring additional powers of illumination into play when the fog thickens upon the sea. Lamps with six concentric wicks have been devised for this supplementary service of exceptional need by Mr. Douglass, the engineer of the Trinity House. Gas has also been for the same reason introduced into lighthouses, principally through the enterprise and ingenuity of Mr. Wigham, of Dublin. He has provided a gas-service in some of the lighthouses of Ireland, in which the light for ordinary night service in clear air is supplied by the flames of twenty-eight gas jets, but in which 108 jets can be lit up in time of fog. There is one lighthouse at Galley Head in which three burners with 324 jets can be all used in great emergency. The electric light is a more powerful source of illumination than gas. The Gramme machine, which furnishes the light of the clock tower at Westminster Palace during the sitting of Parliament, gives an illumination equal to that of 900 Argand flames, or of 7,200 candles, and the Siemens machine is competent to furnish even as much light again as this. It is a part of the principle, which is being gradually introduced, of arranging electrical illumination for lighthouses, that there shall always be additional machines in reserve, to be turned on in times of exceptional emergency.

But it is still only in circumstances of the prevalence of a moderate amount of haze that increased intensity of illumination can be of any practical avail. With dense fog the brightest lights that can be supplied are useless at very limited distances. On this account sound-signals have to be chiefly relied upon; when lights cannot be seen, bells, horns, and whistles are employed, and above all, explosions of gunpowder, with more or less of success, and in recent years exact experiments have been instituted to ascertain the best form of gun for giving fog-signals by sound at long distances. Short bronze howitzers, carrying a charge of three pounds of gunpowder, were first employed, because it was thought that bronze would give a better sound than iron, on account of its near affinity to bell-metal. Professor Tyndall, however, soon demonstrated that the bell-like ringing of such guns is lost long before the noise of the actual explosion of the powder. Major Maitland, of the Royal Artillery, was then struck with the happy idea of causing the gun to issue its warning note through a speaking-trumpet, and a fog-signal gun was devised with a trumpet mouth, such as is represented in the following diagram (Fig. 1).

This gun is loaded at the breach, and contains a series of chambers (C), which can be brought into play in rapid succession after the manner of a revolver. The bell-mouth (T) projects the sound over the sea in the direction in which the warning is especially required. It plays the same part with the sonorous vibrations that the lenses and prisms of Fresnel accomplish with the luminous vibrations of the lantern. Soon after the invention of Maitland's gun, a further important step was made by the discovery that gun-cotton communicates a more rapid and more energetic shock to air than gunpowder, and on that account generates a more space-penetrating sound when it is made to explode. A compressed slab, containing a single pound of gun-cotton, fired in the open air, and without any inclosing chamber, in some carefully executed comparisons, gave a more audible and satisfactory sound at a distance of thirteen miles than three pounds of powder fired with the Maitland gun. The slab in these experiments was placed in the front of a cast-iron reflector, arranged as represented in Fig. 2. unless it was desired that the sound should be heard in all directions around instead of in one specific direction, when the gun-cotton was fired without any reflector.

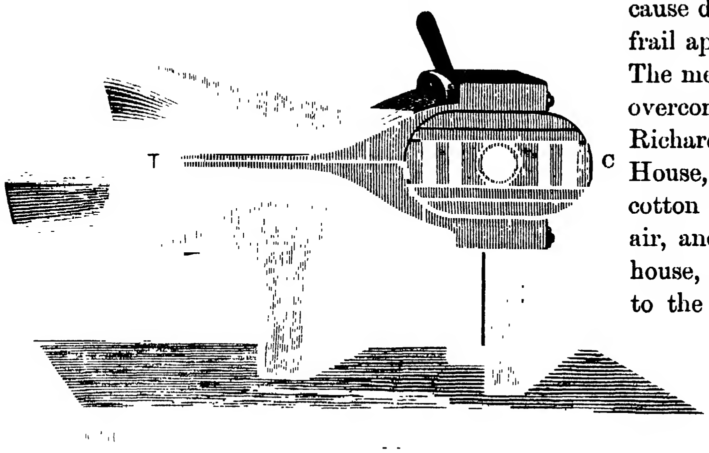

Fig. 1.—Major Maitland's Fog-signal Gun, with a Bell-mouth.

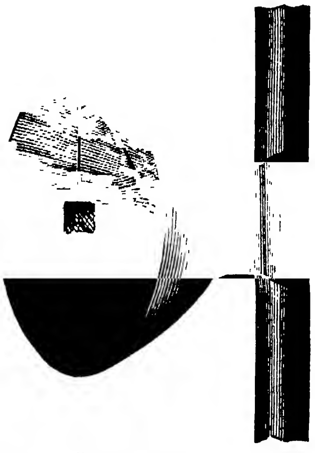

Fig. 2.—The arrangement for firing a slab of Gun-cotton suspended by a Wire in the Focus of a Cast-iron Reflector.

When the notion of the employment of powerful explosives as acoustic signals was first conceived, it was thought that they might be kept ready on hand, and fired from lighthouses on occasions of need. It was soon, however, ascertained that this could in no way be done, because the sudden and intense shock which is incident to the production of a loud and penetrating sound is calculated to cause destructive mischief amidst the delicate and frail appliances used for the maintenance of light. The method by which this difficulty has been finally overcome is due to the ingenuity of Admiral Sir Richard Collinson, the Deputy Master of the Trinity House, to whom it happily occurred that the gun-cotton might easily be conveyed high up into the air, and well away from the lantern of the lighthouse, before it was exploded, if it were attached to the head of a rocket. It is obvious that by this simple expedient the explosion may be so managed as to shed a distinctly audible sound over a very wide range of the sea. The plan was first fairly put to the test of trial at the firework manufactory at Nunhead, and shortly afterwards at Shoeburyness, when rockets charged with $7\frac{1}{2}$ lbs. of compressed gun-cotton were sent up to a great height, and the explosion there brought about. The sound in these cases was distinctly heard eight miles away. Similar experiments have more recently been made in which the explosions were heard twenty miles, and in one instance twenty-six miles away. The success of these trials has been so complete that there is no longer any doubt this is the direction in which the problem of an efficient service of fog-signals in connection with lighthouses will finally be solved.

For a long time it was believed that sound, as well as light, is impeded by dense fog, and that acoustic signals would be materially interfered with from this cause. This doctrine originated in a memoir printed in the "Philosophical Transactions" for 1768, in which it was affirmed that the power of a fog to arrest sound was strictly in proportion to its capacity to impede the transmission of light, and the fallacy has only quite recently been disproved by the observations and experiments of Professor Tyndall. In one memorable instance, on the 13th of December, 1873, it was observed that sound was singularly distinct during the prevalence of a dense fog upon the Serpentine, in Hyde Park, London, and that it became faint as the fog cleared away. Upon another occasion a whistle sounded at the eastern end of the Serpentine was heard upon the bridge crossing the water four times more plainly during a dense fog than when the air was clear. Mr. Douglass, the engineer of the Trinity House, at another time distinctly heard at Milford Haven the firing of guns at the Smalls

Rock in the Bristol Channel, twenty-five miles away, during the prevalence of a very dense fog. Mr. Derham, the author of the paper already alluded to, also considered that both rain and snow impeded sound; but this too is now known to be wrong. There are numerous well-authenticated instances of sound having been heard with remarkable distinctness, both during heavy falls of snow and during tropical downpours of rain. It is not the presence of water, whether in a solid, liquid, or granular form, which offers an obstacle to the passage of sound through air, but varying and heterogeneous conditions of the air itself—the presence of regions of unequal condensations and rarefactions succeeding each other. With such a series of irregular and varying air-strata to pass through, the free play of the sonorous vibrations is embarrassed and confused, and a condition of atmosphere brought about which Professor Tyndall has expressively characterised by the term acoustic opacity, and which is quite commonly met with when the air is of faultless and absolute transparency for all visual purposes. The unequal heating of air does far more to render it impervious to sound than any amount of mist, rain, or snow with which it can be charged. Professor Tyndall illustrates this fact in his lectures at the Royal Institution by a very pretty and striking experiment. He arranges a series of horizontal gas-tubes, pierced with minute holes for the formation of gas-jets, parallel with each other, somewhat as shown in the diagram (Fig. 3), so that when the gas-jets are lit there are layers of hot air rising above the jets, and separated from each other by cooler spaces ranged wall-like between. He then lights a sensitive flame at one side of the apparatus (as at A) and sounds a shrill whistle at the other side (as at B). The flame flickers and dances to the sound of the whistle so long as the intervening gas-jets are not alight. But the instant they are lit the flame burns steadily, and without flicker, at A, although the whistle may be screaming at its loudest, because the sonorous vibrations of the air set up by the whistle at B are then prevented from getting across to the flame at A through the alternate layers of comparatively rare and dense air that lie side by side between the whistle and the flame. The experiments and observations which have shown that haze and fog do not materially obstruct the transmission of sound have a very satisfactory and encouraging bearing upon the scheme of organising a regular system of fog-signals by sound at dangerous and frequented parts of our roadsteads and coasts. Such signals, of course, are not capable of furnishing the same exact guidance by night to vessels approaching land that lights from fixed lighthouses do, but they are quite competent to give most valuable warning of the close neighbourhood of danger at times when the light-signals are temporarily obscured.

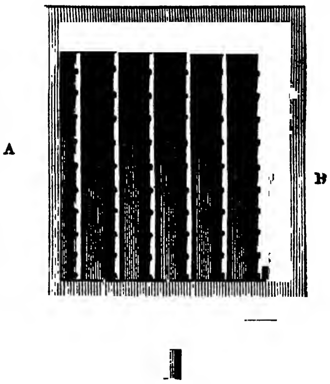

Fig. 3. Professor Tyndall's Experiment for the production of Acoustic Opacity in Air.

THE MOVEMENTS OF LIVING BEINGS.

By Dr. Andrew Wilson, F.R.S.E.

PERHAPS the most characteristic feature of living beings at large is their power of acting and moving in greater or less degree. With the possession of life, we come, well-nigh unconsciously, to associate the idea of motion and action, as opposed to the inert existence of the inorganic thing; and even the stillness of the animal which has ceased to live strikes us as the most plainly marked of all the signs of death. If growth—as we have seen in a previous paper*—or the power of adding to its substance and of converting the matter added into itself, be a prevailing feature of life-possessing things, movements of one kind or another produced by and from within the organism are equally noteworthy as the special belongings of living beings. It is through this inherent power of motion that most animals and not a few plants manifest their plainest title to be called living; and it may fairly be said that an understanding of the various movements and sources of motion in living beings forms a fitting introduction to, as well as an essential part of, all sound biological teaching.

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* "Science for All," "Growth," Vol. II., p. 201.

It may at the outset be alleged that a universal power of movement is by no means characteristic of life at large. The tyro in zoology can point in support of this assertion to very many cases already dealt with in these pages,* in which those animals of by no means the lowest rank are as thoroughly rooted and fixed as plants; and it might be urged that the great fields of vegetable life present us with a denial *in toto* of the statement that life and motion are convertible terms. It is perfectly true such animals as sponges, corals, sea-squirts, and even the familiar oyster, are as firmly rooted in their way as trees; and such cases, we repeat, might seem to present us with grave exceptions to the dictum first laid down regarding life and movement. But it is a characteristic of science that frequently its research begins where ordinary observation ends. Fortifying itself with the microscope, and aided by a knowledge of the possibilities as well as the probabilities of life's action and powers, science demonstrates the futility of judging things by commonplace standards and by the means applied to resolve the difficulties of everyday existence. Looking deep within the tissues and parts of the fixed and rooted animals just mentioned, the scientific gaze would detect, as we shall presently see, movements of elaborate and extensive kind. The oyster or sea-squirt, itself apparently a fixed motionless organism, may be shown to be a veritable centre of the busiest living industry. A glance backwards into the development and prior history of one of these rooted beings, from sponge to oyster, would show that each begins its life as a free-swimming active particle. If quiescence be the rule of such existences, it is merely a superficial stillness after all, and the tides and currents of life ebb and flow as plainly and as forcibly, to the scientific understanding, in the oyster or coral as in man. Nor may we call a halt thus, in our preliminary objection to the idea that apparent stillness in living beings is to be regarded as indicative of real quicesence and inertness. The plant itself, a rooted and fixed organism, which gives no sign of vitality even if it be torn to pieces, can be demonstrated to possess, beneath the surface of its wonted stillness, as active and mobile an organisation as the animal. We do not now refer to such plants as the sensitive plants, or *Mimosæ*, the Venus' fly-trap (*Dionæa*,) or other vegetable organisms, whose movements are much more conspicuous than those of many animals; which droop their leaves on the slightest touch;† which capture insects for food as deftly as does a spider; and which, most wonderful of all perhaps, may be chloroformed and narcotised as animals. Such cases of plant activity and movement, although perfectly well known and fully recognised, are exceptional in their occurrence, and leave apparently the ordinary inert course of plant existence unaffected by their curious development of sensation and movement. But beneath the ordinary course of vegetable existence runs a constant undercurrent of active movements, all unknown to and unperceived by the outside world. Within the tissues of every plant there is as busy an economy as that illustrated by the inner life of the animal, and it only requires the assisted eye to correct the judgment of that "unassisted sight" which, proverbially dull to the beauty of life, is no less obtuse where the recognition of more important features of living structure is concerned.

We may find a fair starting-point for our researches into the movements and internal activities of living beings in a simple study of the actions which the microscope reveals to us as occurring within the tissues of well-known plants. For instance, there is no structure which makes a more pronounced appeal to us in the way of painful practical botany than the stinging hair of a nettle. A nettle hair, the structure of which has been already described,‡ is an appendage of the nettle leaf, but, unlike the ordinary hairs which we see coating the surface of the many leaves, it possesses at its base a kind of gland or secreting structure, which manufactures the irritating fluid that is practically the nettle's poison. The point of this hair is extremely delicate. The slightest touch breaks the point, and the poison fluid with which the hair is charged at once flows into the skin, and produces there the characteristic pain and after-effects. Thus a nettle stings as a serpent stings; both possess an apparatus consisting of a poison-gland and a fang—the latter being the "hair" in the nettle, and a hollow tooth in the snake. But the living nettle hair has a more curious aspect and history than those included in the recital of its offensive powers. When placed under a sufficiently high power of the microscope, the nettle hair, which, like the nettle itself, might be regarded as an inert structure exhibiting no sign of life or activity, is seen to be a perfect centre of curious and interesting movements. The contents of the hollow nettle hair—or, more strictly speaking, its lining—are seen to exist in a state of continual motion. There are waves of contraction which roll like the billows of the ocean along the whole length of the hair; and there are minor streams of granules which hurry here and there with varying speed through the substance of its interior. Main currents may be traced around the margin of the structure, and that there are many minor currents hidden from the highest powers of our best microscopes no one may doubt. Thus the nettle hair is a very centre of active movements and of an incessant circulation of its particles and fluid, such as we could not dream existed within the apparently stable and inert plant-form.

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* "Science for All." "What is an Animal," Vol. I., p. 373.

† "Science for All," "Nerves or no Nerves," Vol. I., p. 174.

‡ "Science for All," "A Nettle Sting," Vol. I., p. 338.

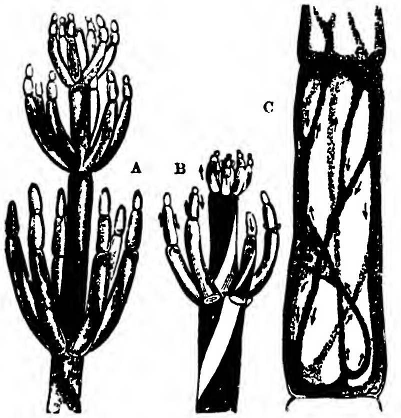

Fig 1.—A, B, Circulation of Protoplasm in Chara; and (c) in a Cell of a Hair of Tradescantia.

The nettle hair stands not alone in its wonderful activity. There, for instance, is the well-known *Chara*, a water-plant, composed of rows of minute cells (Fig. 1, A, B). Within each one of these cells a circulation as active as that of the nettle hair is to be viewed; the currents passing up one side of the cell and down the other in rotatory movement. The cells of the Virginian spider lily (*Tradescantia*) exhibit the same phenomenon; but in the latter the currents traverse the cell in thread-like tracts across its substance (Fig. 1, C). The currents here are, moreover, irregular in their movements; occasionally they may be seen to be arrested for a moment, then they again commence their motion, striking out into new ways and paths through the substance-matter in the interior of the cell. That common water-weed, *Anacharis*, which, imported from America comparatively few years ago, has overrun our ponds and canals (p. 3), also exhibits in its leaf-cells similar movements; whilst in that curious water-plant, the *Vallisneria*, of Southern Europe, the currents are seen to sweep round and round within each cell, setting free the green chlorophyll grains in its sweep, and impressing the observer with an idea of ceaseless and powerful activity.

The explanation of these curious movements in the cells of plants—revealing to us a literal world of activity concealed beneath the apparently stable front of plant life—is to be found in the fact that the contents of these cells include a layer of that universal "basis of life" known to every one under the name of *protoplasm*. It is no theory, but the most stable and most fundamental fact of life-science, that life is nowhere known to exist save in connection with this jelly-like matter. Whatever be the exact relation between protoplasm and life—one of the "vexed questions" of biology—this much is certain, that only through protoplasm of one kind or another is life exhibited. Thus, in the cell of the nettle hair, or in the other vegetable cells just described, the protoplasm or living matter occurs as a delicate inner layer of the wall of the cell, and the cause of the currents is believed by many biologists to exist in the contractions of this delicate living cell-lining. This latter is a likely explanation; and in any case the origin of the movements may logically enough be referred to the protoplasm of the cell, for wherever this protoplasm exists, motion is its universal characteristic. It has even been alleged by high authority in botany that the little solid particle called the *nucleus*—seen in most cells (Fig. 2), and itself a protoplasmic speck — creeps about within the cell much after the fashion of the animalcule to be noticed presently, and known as the *Amœba*. This movement of the nucleus is also believed to possess a large share in affecting the currents which, common microscopic observation shows, pass incessantly through the cell-substance.

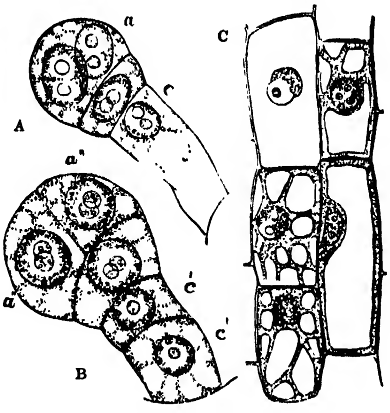

Fig. 2—A, B, Embryos in the Embryo-sac of Allium Cepa; the Cells contain very large Nuclei each with two Nucleoli—A, the spherical apical Cell contains two Nuclei, *a*; in B *a* has already divided into *a'' a''*, and in the same manner *c* has split up into *c' c'*. C, Parenchyma Cells (Cellular tissue) from the central cortical layer of Fritillaria imperialis, and longitudinal section × 550, showing Nuclei.

Now this unceasing turmoil in the living contents of the cells of the nettle hairs, and of the cells of other plants, is to be regarded as by no means of singular occurrence in the plant world. On the contrary, we must consider these movements as universal in their nature. Wherever we find life there protoplasm must be; and the most exact observations show us that everywhere living protoplasm is in a state of constant movement. Just as the latest notion in physics resolves the gases or ether around us into a collection of ever-moving atoms, so in the world of life, incessant movement is the characteristic feature of protoplasm, and consequently of life. Extending our view from the pond-weed and the nettle over the whole vegetable kingdom, we come to see that incessant motion must be as much the heritage of plant life as of animal existence. From the fungus or the lichen staining the wall with its pleasant hues to the lordly oak—from the humble moss to the giant sequoia of California itself, towering its head some hundreds of feet above the soil—we may discover no break in the sequence which connects life with movement as its unfailing accompaniment. The tree or the moss gives no outward sign of vitality, it is true; slow growth and the changes of leaf, flower, and fruit marking the progress of the seasons are but passive marks of life, after all. But hidden within the tissues of lichen, moss, tree, and flower alike, all invisible to the unassisted sight, are not merely probabilities, but realities, of living movement. Coursing through the living contents, or protoplasm, of cells and vessels, are these wondrous currents, carrying with themselves the vested interests of plant nourishment and of plant sensation likewise. So that the great forest, through which no sound passes save the sough of the wind, the hum of insects, or the chirp of birds, is in reality a great repository of movement; and the truth of the idea becomes plain, that, were our hearing powers magnified as our powers of sight may through the microscope be increased, we might be stunned by the sound of these life currents "as with the roar of a great city."

Passing from the plant domain to the confines of the animal world, we enter a sphere in which movements of apparently very varied kinds are not merely known to occur, but are plainly perceptible. Within the human economy, for instance, are exemplified most, if not all, of the varieties of movement seen in lower forms of life. A simple study in human physiology may, in other words, present us with a summary and illustration of the means of movement seen in lower existences. Mankind in this respect may be said to be the epitome of the entire world of life. It may, however, at this stage of our inquiries, be well to enforce the observation that there is nothing essentially different in the forms of movement seen in higher life from those found in lower animals, or, for that matter, from the movements we have witnessed in plants. On the contrary, every fresh accession to our knowledge has made plainer the fact that animal motion, like plant movement, can be referred backwards to the contractions of protoplasm in some form or other. It may happen that the moving structures may not at first be recognisable as protoplasmic, but sooner or later research filters out, so to speak, the essential elements of motion into this curious ever-present matter of life. When in the act of writing one's fingers and arm move, the act is referred to the contraction of the muscles of the limb; just as, on a similar basis, we explain every ordinary act of existence, from the winking of an eyelid to running a race. But the question still faces us, "What is muscle?" and in its reply, we may perchance discover that the essential elements of muscle are of the nature of protoplasm, and that between the currents in a nettle hair and the movements of our own limbs there are bonds of relationship of the closest and most intimate kind (Vol. I., p. 368).

Our study of animal movements may be commenced by a brief recital of the nature of a species of motion common in lower forms of animal life, and represented by certain curious facts of human physiology, and of that of higher animal life at large. When a thin film of human blood is examined, that fluid is seen to resolve itself into two distinct parts—a solid and a fluid portion. The latter consists of a fluid as clear as water, and named the *serum*, or *plasma*. The former consists of innumerable small bodies (Vol. I., pp. 366–7), varying in diameter from the $\frac{1}{2500}$th to the $\frac{1}{3500}$th of an inch, and termed the *corpuscles*. These are of two kinds, *red* and *white* corpuscles. The former give the red colour to the blood. They are so numerous that as they float in the blood the unaided sight is unable literally to see the colourless fluid between them, and hence blood appears to us as a uniformly red fluid. The *white corpuscles* are a little larger and less numerous than the red, and each, moreover, contains in its interior a solid speck, the *nucleus*—which is wanting in the red ones. All higher animals (save the little fish called the Lancelet) have these two kinds of blood-corpuscles. In the Lancelet and in Invertebrate animals only white corpuscles occur. What is known of man's white corpuscles equally applies to those of all other animals, and the chief fact of interest concerning these bodies is readily appreciated. When a thin film of human blood is kept on a microscopic slide at the normal heat of the body and blood (100° Fahr.), the white corpuscles may be seen to undergo certain remarkable changes of shape. At first round, the corpuscle soon alters its shape by thrusting out its substances into well-marked processes, and, continually changing its shape in this way, the corpuscle may be seen to move across the field of the microscope as if it were some peculiar form of animalcular and independent existence. In the white blood-corpuscles of the newt, which are much larger than those of man, we see the same phenomenon. Those of the crab likewise contract and alter their shape; and in all white corpuscles, indeed, the same curious fact of movement by contraction and alteration of shape may be noted. It is curious to reflect that in our veins and blood-vessels at large there exist myriads of these particles, representing in their way the constituent parts of blood, and exhibiting movements which might be regarded as more properly those of independent life.

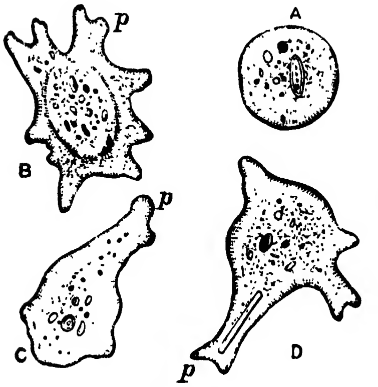

Fig. 3. -Amœba.
A, Contracted; B, C, D, in Motion; p, Processes thrown out in action.

Let us now select from the domain of lower animal existence a very familiar animalcule known as the *Amœba* (Fig. 3), to which under another aspect of its life, we have already alluded (Vol. I., p. 176). The *Amœba*—a name derived from the Greek for "change"—occurs in stagnant water, in infusions of decaying matter, and like places. It varies in size—a common measurement being $\frac{1}{500}$th of an inch in diameter. When placed under the object glass of the microscope, the amœba is seen to comport itself in an exactly similar fashion to the white blood-corpuscle. Now, the animalcule may appear of a rounded form; in a moment, it has shot out from its substance processes and projections which convert it into the similitude of some solitary island, with peaks and promontories jutting out in a sea of its own; next it has "flowed," so to speak, from this shape to another, in which it assumes the likeness of a star; soon this latter form gives place to that of an oval, and this in turn to the island-shape again. And thus perpetually changing its shape—of no form or of every conceivable conformation—the animalcule, now plainly seen, and now almost fading away into dim nothingness, well merits its name—*Amœba*—"change." When a food-particle approaches and touches the margin of its body, that body acts, though all unconsciously of course, upon information received, and surrounds the morsel with the processes of its body, thus engulfing the particle, which is finally deposited within its substance, and there, despite the want of digestive apparatus, duly digested.

So much for what we see in the amœba of our stagnant pool. The likeness of the animalcule to the blood-corpuscle of our veins is so marked that it cannot escape the most casual observer. We name the blood-corpuscle's movements *amœboid*, or "amœba-like," because they are, *de facto*, those of the animalcule. The motion of an amœba is, in fact, the type of all such movements, and when we inquire into their nature we find ourselves once again face to face with the protoplasm of our nettle hair and our anacharis leaf. For the blood-corpuscle of our veins and the amœba of the pool are simple specks of protoplasm, alike in chemical composition and physical properties, so far as the furthest science can detect. We explain the changes to which an ambœa is subject by saying that such movements are a primary property and heritage of the protoplasm of which the animalcule is composed, and we must assume the same of the white blood-corpuscle. This statement does not, it is true, lead us to the exact origin of the movements; but it is something to have discovered and to know that contraction and movement are properties of protoplasm, whether we find it in the animalcule or in the man.

Lastly, and as if to complete still more clearly the parallelism between the amœba and the white blood-corpuscles, we find that the latter wander through the tissues of our bodies, escaping through the walls of the blood-vessels, just as amœbas wander through the water in which they live. It is believed, indeed, by some physiologists that these wandering blood-corpuscles may serve to afford nourishment to the tissues at large; but apart altogether from their functions, the identity of the amœba's movements with those of the blood-corpuscles is complete, unmistakable. and remarkable.

Yet another form of movement is common in man, in higher animals generally, and in very many lower forms of life. When the lining membrane of the windpipe is examined, or when the ear-passages and brain-cavities are investigated by aid of microscopical inquiry, the surface-layers of these parts are seen to be composed of certain elongated cells, attached to the margin of each of which is a number of very fine hair-like filaments called *cilia** (Fig. 4). Let us bear in mind the minute character of these cilia. The average length of a cilium is $\frac{1}{3200}$th of an inch; that is, it would require 3,200 cilia placed in a line to equal an inch in length. The cilia are flattened in form, and taper towards their free or unattached ends. Close observation shows that the cilia seem to pass into and to become continuous with the contents of the cell which bears them, and as these contents are protoplasm, we have good reason for the belief that cilia are in reality microscopic or infinitesimally small threads of this substance. Moreover, an additional feature supporting this view is found in the fact that cilia may be seen to change into protoplasm "processes," like those the amœba shoots forth from its substance; whilst, conversely, such processes are also noticed occasionally to become cilia.

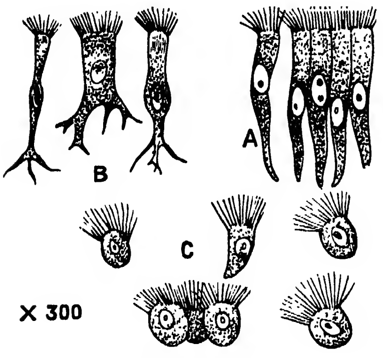

Fig. 4.—Cilia.
A, From Human Nasal Membrane; B, From Cat's Trachea; C, From Frog's Mouth.

The great interest which attaches to cilia, however, resides in their incessant motion. Except when dead, a cilium is never at rest. These filaments wave continually backwards and forwards, and thus perform the all-important function of creating and maintaining currents in air or water, as the case may be. Thus the cilia which line our windpipe cause, by their vibration, the fluid secretions of the lungs and windpipe to pass upwards to the mouth. The fluids of brain and spinal cord are similarly kept in motion; and the air in the ear-passages is likewise kept in circulation. This incessant movement of these microscopic filaments—all unknown, be it remarked, to the non-physiological section of mankind—thus plays an important part in maintaining animal existence. How, it may be asked, do cilia move? Primarily, we are driven once again to the power of movement which characterises the protoplasm of which they are composed. The cilia, so far as we know, do not contract or shorten themselves; they merely bend, as it were, and then raise or straighten themselves—much as the stalks of corn bend and rise beneath the gentle breezes of the autumn-time. The fluid they are destined to move flows in the direction in which they bend; and this is explicable if we suppose—and the supposition is founded on observation—that a cilium bends more quickly and with greater force than it erects itself; the fluid being thus driven onwards, whilst the less powerful back-stroke of the cilia will not materially affect the current. Cilia are not dependent on nerves for their movements, which may continue long after the death of the animal possessing them. I have seen the cilia of a mussel's gill move faintly, in summer, twenty-four hours after the gill had been detached from the animal. Their movements may be very rapid. Twelve contractions per second is a rate which has been observed in the frog; and other computations set the movements, in some cases, at 720 per minute.

Where are cilia found in lower life, and what functions do their movements discharge, is a query of an important nature. Here is a fresh-water mussel or an oyster. Place it in its native water, with some indigo or carmine powder strewn therein. Soon we become aware of the existence of currents in the water, and we see the coloured stream drawn in at one side of the shell, and ejected at the other. Examine the mussel, and you find its gills literally bristling with cilia (Fig. 5, *c*). The mussel, and indeed all its fellow-molluscs, are indebted to cilia for their power of sweeping in fresh water for breathing, and for that of sweeping out from their gills the effete water already used in that process.

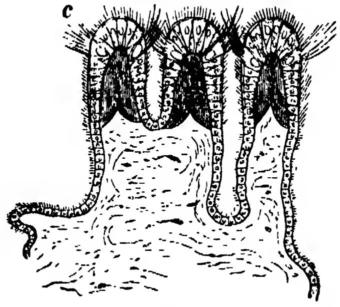

Fig. 5.—Gills of Mussel. (*Highly magnified.*)

Here is a single animal of a colony from the sea-mat class. Its tentacles are fringed with cilia, and its body inside is lined with them. As external belongings of the sea-mat animal, they assist the capture of food; and they discharge internally the functions of a heart. The sea-squirt† rooted to the rock at once draws in food and water by its ciliary currents; and a living sponge,‡ equally fixed and immobile, is found to be in reality a "submarine Venice," whose protoplasm inhabitants, lining the canals, incessantly sweep in currents of water by aid of their cilia, and as incessantly sweep this water onwards and outwards into the ocean wastes again.

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* Latin, *cilium*, an eyelash.

† "Science for All," Vol. IV., p. 57. ‡ Ibid., Vol. I., pp. 56, 59.

Here is a wheel-animalcule, one of the *Rotifera* (Fig. 6). It swims rapidly through the water, propelled by the cilia that fringe its head-extremity, and which, appearing like revolving "wheels," give this group of animalcules its name—although, be it noted, the cilia do not revolve, but merely bend, each in its turn, and thus cause the illusion of a rotating wheel. The cilia here constitute the organs of motion, and when the animalcule fixes itself by its tail, the cilia, continuing to work, then serve as organs for sweeping food into the mouth. So also in the animalcules, named *Infusorians*, we see in every stagnant pool. The margin of the body is fringed with them in that *Paramæcium*, which paddles its way swiftly through the yielding waters. There, in these stalked *Vorticellæ*, or "bell-animalcules," the cilia fringing the bell draw particles of food to the mouth; and that *Stentor*, or "trumpet animalcule," when fixed, likewise uses its cilia as food providers, and when free-swimming, as oars. Even in the lower plant-worlds we see cilia as the prominent organs of motion. *Volvox globator*,* a true plant colony, rolls onwards, propelled by ciliary movement; and the germs of seaweeds are as active as animalcules, owing to their cilia-fringed bodies. And if we are asked "Whence this power of movement?" we are once more referred, by the logic of facts, to the protoplasm of which the cilia are composed as the material and medium through which these curious filaments carry on their incessant vibrations.

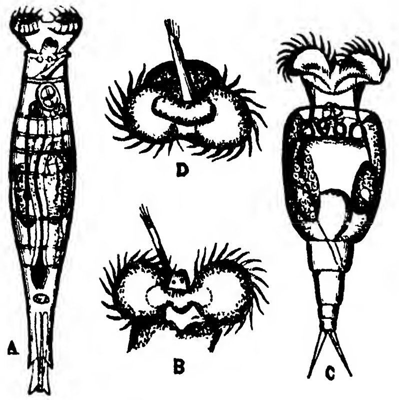

Fig. 6.—A, Rotifer vulgaris; B, Vibratory Zones or "Wheels" of ditto; C, Rotifer inflatus; D, Vibratory Zones of ditto.

The ordinary actions of our bodies, as before remarked, are carried out through the contraction of *muscles*. *Muscle*, or *muscular tissue*, forms the "flesh" of animals. We eat the muscle of the ox when we dine on beef, and what we value for food in a haddock or sole is muscle likewise. Muscle is therefore the tissue of primary importance in executing visible movement in the animal world. But this tissue, in virtue of its movement, performs other duties, which, at first sight, we are not accustomed to think of as identical with the motions of our legs and arms. For instance, by muscular action our blood is circulated—for the heart is simply a hollow muscle. The emotions are expressed by contractions of the facial muscles. The food is mixed with the gastric juice and propelled along the digestive system by the muscular action of stomach and intestine; and lastly, speech itself is largely a muscular act.

The body or organ we name a "muscle" is composed, firstly, of bundles of fibres, each bundle termed a *fasciculus*. Each fibre is composed of smaller fibres, or *fibrils;* and these, again, may be divided into still smaller fibres, the *ultimate fibrils*, which are not capable of being divided into anything smaller, and which therefore in themselves represent the elements of which the muscle is built up.

When a muscle acts, it does so by *shortening itself*, and by thus bringing together parts between which it is attached. This property of muscle is called *contractility*, and an important step in the physiology of muscle was gained when it was proved that this property is not a something imparted to muscles by nerves, but a power *inherent* in the muscle. In other words, as cilia are contractile in themselves, so also is muscular tissue. What nerves do, is merely to *stimulate* this contractility, and to incite it to action. Now to what is the muscular power of our bodies due—in other words, what is the exact seat of muscular contractility? The answer to this question is by no means far-fetched. Muscular fibres, let us note, begin their existence as simple *cells*, each consisting of a mass of protoplasm, and of a nucleus like the white blood-corpuscle. As the development of the muscle proceeds, these cells become first rounded, and next become lengthened to form the fibres we see in the muscle. Each fibre of muscle is in fact developed from a single cell, and it is the original protoplasm of the cell that is gradually transformed into the cross-bands we see in ordinary muscular fibre when we place it under the microscope. We have no space at command wherein to discuss the differences between one muscle and another—that is mere matter of elementary physiology. What is more to the purpose is to impress on our minds that this last and highest development of contractile tissue in the animal world is, after all, merely the high elaboration of the same protoplasm we see in a blood-corpuscle, and practically similar to that we behold in amœba.

In conclusion, then, we may summarise what we have learned respecting the movements of living beings by saying: firstly, that they depend on the presence of *protoplasm*, the universal basis of life; secondly, that the simpler movements in plants and in lower animals are due to contraction of simple or unspecialised protoplasm, such power of contraction being a property of this substance; thirdly, that the varied movements seen in higher and lower animals alike—*amœboid*, *ciliary*, and *muscular*—are merely modifications and elaborations of protoplasm-contractility, and fourthly, that all forms of movement thus originate from a common basis.

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* "Science for All," Vol. I., pp. 353, 376.

Thus a wide view of even a single function of living beings demonstrates anew their wonderful unity, which, long suspected of old, is now but being unfolded more cleary by the latest research.

ANIMAL HEAT.

By Dr. E. Waldemar von Tunzelmann.

MANY of the phenomena relating to this subject form part of our daily experience. Our sensations regarding temperature are continually varying: at one time we feel uncomfortably warm, at another uncomfortably cold, and we say accordingly that we are warm or cold; at other times our temperature sensations do not obtrude themselves upon our notice—*i.e.*, we are in a medium comfortable condition. Again, we observe that our temperature sensations are not entirely dependent upon surrounding conditions, though largely influenced by them: thus we may be very warm on a cold winter's day, while in the height of summer a person suffering from ague may be shivering with cold. We may notice also that the information which we obtain regarding the temperature of surrounding objects by touching them is entirely relative. We can tell only whether they are warmer or colder than that part of our body with which we touch them, for if they are at the same temperature they do not give us any sensation of temperature; thus some object may at one time feel cold, at another warm, without its temperature having changed at all, or the same object may feel warm to one part of our body, cold to another part. This is well illustrated by the following experiment:—Take three basins, fill one with cold water, another with warm—as warm as can be comfortably borne—and the third with water at a medium temperature, then put the left hand into the cold, the right one into the warm water, and leave them there until they cease to feel cold and hot respectively; then take them out, and rapidly plunge them into the lukewarm water; the right hand will feel cold, the left one warm—*i.e.*, the water feels cold to the hand which was warmer than it, and warm to the hand which was colder than it. Thus we see that in order to find out the actual temperature either of ourselves or of surrounding objects, we must use the thermometer. The use of this instrument reveals to us a fact of the utmost importance, viz., that in spite of our feeling at one time very warm, at another very cold, our real temperature is almost invariable as long as we are in health. Into the phenomena of disease we will not enter. This does not apply merely to an individual living in a country in which the temperature is tolerably uniform for considerable periods of time; it applies to the whole human race. If we put the bulb of a thermometer under the tongue of an Eskimo in the frozen north, or of a negro under the blazing sun of the tropics, we find that in each case the temperature is almost the same, the difference not amounting to one degree. The average normal temperature of a human being is about 37·6° Centigrade (99·5° Fahrenheit). In any one individual there is a slight diurnal variation, the maximum temperature being during the day, the minimum at night, but the whole range does not exceed two-thirds of a degree. Nor is this confined only to man; it applies to all the so-called warm-blooded animals, including all birds and mammals. Every warm-blooded animal has a normal temperature, which varies only within very narrow limits, but this temperature is not the same for each species; thus the normal temperature of the swallow is about 44° C., that of the wolf about 35·25° C.

Turning our attention now to the other lower animals, viz., reptiles, amphibians, fishes, and all invertebrates, like snails and crabs, we find quite a different state of things. None of these animals have a constant temperature, and, with a very few exceptions, their temperature is only slightly above that of the medium in which they are placed, air or water; thus the temperature of the frog is usually only about ·05° C. above that of the atmosphere. These animals are commonly spoken of as "cold-blooded," in contradistinction to the "warm-blooded" animals mentioned above, but the term is obviously ill-chosen. The blood of a "cold-blooded" animal is not necessarily cold, it is only not much warmer than that of the surrounding atmosphere, and may be actually warmer than that of a "warm-blooded" animal. For instance, when a lizard is basking on a stone in the full glare of a tropical sun it is exposed to a temperature much higher than would be comfortable to a warm-blooded animal, and its temperature is high in proportion. Again, when a number of cold-blooded animals are collected in a limited space their temperature may rise considerably—*e.g.*, Hüber noticed that at times the temperature in a bee-hive rose to 40° C., *i.e*, higher than the normal temperature of most mammals.

Under certain circumstances the temperature of warm-blooded animals falls to a very low point—*e.g.*, that of a hybernating mammal is very low. The reason of this we shall see presently.

Having now briefly considered some of the chief phenomena which concern our subject, we may proceed to discuss it under three heads. First, then, how is heat produced? Since the temperature of a man is generally higher than that of the surrounding atmosphere, it is evident that his body must be a source of heat. In order to understand how heat is developed in the animal body we will consider for a moment the phenomena presented by a burning candle; the substances which compose a candle are bodies of complex composition, which during combustion combine with the oxygen of the air, and form bodies which are much simpler in character and also much more stable. During this conversion of complex unstable into simple stable bodies, heat, a form of energy, is evolved: hence we may say that the candle was composed of substances of great potential energy, which during its combustion became converted into actual energy, which appeared as heat. This is a picture of what occurs in the body; food consists of substances of very complex composition, which are assimilated by the body, and finally discharged as stable substances of simple constitution, chiefly water and carbonic acid; besides these, the sole product of the combustion of a candle is a crystalline body containing nitrogen, urea. During this breaking down of complex into simple substances energy is set free, and a great deal of it appears as heat. It is not easy to measure directly the quantity of heat evolved by a man's body during the twenty-four hours, but it can be estimated in the following way: it is easy to calculate that the oxidation of the food required daily by an average healthy man living under average conditions would evolve about 23,000 kilogramme degrees of heat—*i.e.*, heat sufficient to warm 23,000 kilos* of water from 0° C. to 1° C. If this heat were used without loss to do mechanical work it would be equivalent to somewhat less than one million metre-kilogrammes—*i.e.*, it would be able to lift nearly one million kilos one metre high. Now, a good day's work for a healthy man, whether it be walking or any kind of muscular toil, is about 150,000 metre-kilogrammes—*i.e.*, about one-sixth the whole energy of the food; the remainder of the total income of energy leaves the body in the form of heat.

It used to be thought that the production of heat in the animal body was precisely comparable to the production of heat by the burning of a candle; that, in fact, just as the oxygen of the air combines with the substance of the candle, so the oxygen absorbed in the lungs combined with carbonaceous material in the blood, so that the heat of the body resulted from a slow combustion taking place in the blood; this view, however, has been abundantly proved to be erroneous; no such, or very little, oxidation occurs, so that very little heat is produced in the blood itself. This leads to the natural question—Where is heat produced? The following facts will throw light on this point:—If a delicate thermometer, or better still a thermopile of peculiar construction (a thermopile is a very delicate instrument used for showing differences of temperature), be thrust into a mass of muscle, and this muscle be then made to contract—*e.g.*, by passing electric shocks through the nerve which goes to the muscle—the thermometer or thermopile will show a distinct rise of temperature; again, if the nerve going to the submaxillary gland† be stimulated, causing a flow of saliva, the temperature of this saliva will be found to be from 1° to 1·5° higher than that of the blood passing through the gland; again, if the temperature of the blood leaving the liver or the brain be ascertained, it will be found to be considerably higher than that of the blood entering those organs. In fact, wherever tissue change is going on, there heat is produced: the act of thinking, which exercises the brain, the secretion of saliva and the other digestive fluids, the beating of the heart, &c., all result in the production of heat; hence, even when a man is perfectly at rest, his body is producing heat. When he is performing muscular work, however, the substance of his muscles undergoes partial decomposition, resulting in a great increase in the discharge of carbonic acid and water from his lungs, and of heat from his body generally. When a man has been working hard for some time he begins to feel tired and hungry, and if food be not supplied to him he becomes weaker and weaker; if, however, he be fed and rested, his strength is restored; this is because the continued contraction of his muscles, and the constant activity of his nervous system, have been accompanied by wasting of the substance of these organs, and he requires food and rest to enable this wasting to be made good, to restore his muscles and other parts of his body to their previous condition.

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* The kilogramme is now so universally used as a scientific weight, that the reader scarcely requires to be reminded that it is equal to 2·205 lbs. avoirdupois.

† "Saliva," "Science for All," Vol. III., p. 308, and Vol. IV., p. 89.

Thus we see that the heat of the body is produced by the activity of its constituent tissues. Now, the blood is not stationary in any organ, but circulates all through the body, so that when warmed in the muscles, or liver, or any other organ, it soon leaves them, and distributes this heat all over the body, so helping to maintain all its parts at a uniform temperature.

How is heat discharged? That our bodies are continually losing heat to the surrounding atmosphere is a matter of common experience. It is in order to check this loss that we wear warm clothing in cold weather, so economising our heat. The loss takes place in various ways; whatever be the temperature of the inspired air, it is noticeable that the temperature of the expired air is nearly equal to that of the body; the expired air is also laden with aqueous vapour, which has evaporated from the blood in the lungs, so that a considerable part of the loss (about 20 per cent.) is due to the warming the expired air and the evaporation of the water of respiration. About 2½ per cent. is lost in warming the excreta; by far the greater part of the loss, however (about 77·5 per cent.), takes place by conduction, radiation, and evaporation from the skin. In connection with this, we may profitably consider briefly the structure of the skin, one of the chief functions of which is to regulate the temperature of the body.

Everybody must have observed that when the skin has been blistered by the sun, or after scarlet fever, its surface peels off in large flakes. This superficial part of the skin is called the *epidermis*, or scurf-skin. It varies in thickness in different parts of the body, from $\frac{1}{240}$ to $\frac{1}{12}$th of an inch; it is very thick on the soles of the feet, and generally over parts exposed to friction. It is thin over the face. When the epidermis is peeled off, the true skin (*cutis vera*) is exposed: it is very sensitive and vascular, and so red. It is composed of fibrous tissue, which is very dense, and closely felted next the epidermis, but becomes looser and laden with fat as it gets farther from the surface. Its surface is covered with small projections called papillæ, which project up into the epidermis. If the palm of the hand be closely examined with the naked eye, it will be seen to be marked by numerous minute parallel lines. These are very well marked on the tips of the fingers, where they have a concentric arrangement; they are due to numerous papillæ arranged in rows. A section of the skin perpendicular to the surface (Fig. 1), shows well many of these points. If the tips of the fingers be examined with a hand-glass, minute orifices are seen along the tops of the ridges, and minute drops of fluid may be seen issuing from them, if the hand be perspiring; these are the mouths of the sweat-glands. In the section a sweat-gland is seen to be a long tube, which passes right through the epidermis—in which it is spirally wound like a corkscrew—and *cutis vera*, and then is coiled up into a ball. If more highly magnified, it would be seen to be composed of a thin membranous wall lined by cubical cells. The sweat-glands are very numerous: one square inch of the palm of the hand contains about 2,800 of them; the same area on the surface of the leg about 400. If a similar section be made of a piece of skin—the blood-vessels of which have been filled with red injection (Fig. 2)—small arteries will be seen in the *cutis vera* breaking up into very numerous capillaries, from which small veins arise; each papilla nearly has a small branch of artery running to it, and forming a capillary plexus in it.

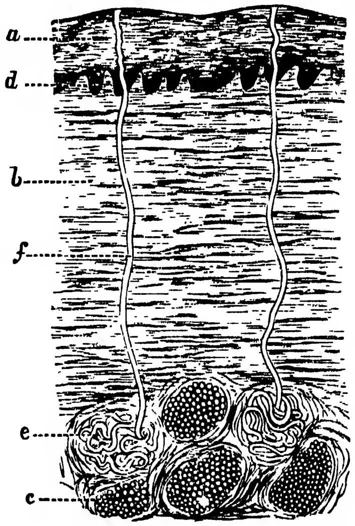

Fig. 1.—Vertical Section of Human Skin. (*Magnified 20 times.*)

a, Epidermis; *b*, Cutis Vera; *c*, Fat-Clusters; *d*, Papillæ; *e*, Sweat-glands; *f*, Sweat-duct.

A close capillary plexus will also be seen round the coiled part of each sweat-gland. Small nerves may also be seen, and here and there one will be seen to enter a papilla, and end in an ovalish body—a tactile corpuscle. These are very abundant in the palm of the hand, and it is to them that the skin owes its tactile sensibility.

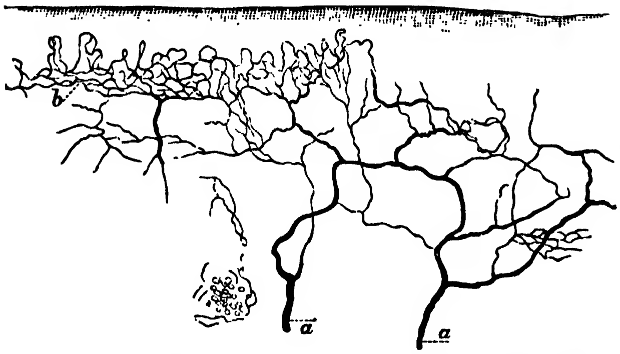

Fig. 2.—Blood-vessels of a Piece of Skin from the Front of the Thigh. (*Magnified 20 times*).
a, Small Artery; *b*, Capillary Plexus.

Since the skin is so richly supplied with blood-vessels, it is evident that the warm blood coming to it from the internal parts will become cooled in it, by radiation and conduction, so that a great deal of heat is thus lost through the skin. The rosiness on the cheeks of persons in robust health is due to the epidermis there being so thin as to allow the red blood to be seen through it. Some persons are always pale, even when in robust health, and this is generally due to the epidermis on their cheeks being thick; the pallor of persons in bad health is commonly due to the poverty of their blood, which has lost its natural bright-red colour. In the former class of pallid persons, if the lower eyelid be everted, its inner surface will be found to be almost scarlet, owing to the numerous blood-vessels being very close to the surface.

We are now in a position to discuss one of the most important channels for the discharge of heat. One of the most striking consequences of violent exercise is that the skin becomes red, warm, and moist; the moisture collects into drops, and in extreme cases may seem actually to stream from the skin. The redness and warmth of the skin are of course due to increased vascularity, the moisture is due to the secretion of the sweat-glands becoming so abundant that it is not evaporated as fast as formed, but collects in drops; the evaporation of this moisture is very efficient in cooling the body. In health the sweat-glands are always secreting; as long as their secretion is evaporated as fast as formed it is not perceptible, and so is spoken of by physiologists as the "insensible perspiration;" as soon, however, as it is not at once evaporated, but appears in drops, either from its being secreted in increased quantity, or from the air being so loaded with moisture as to be unable to absorb any more, or from both these causes combined, then it becomes evident, and is spoken of as the "sensible perspiration." Healthy human sweat is a faintly alkaline fluid, consisting chiefly of water, with a little common salt, fats, &c. The sweat-glands, like the salivary-glands, are supplied by nerves, which bring them under the control of the central nervous system; their increased activity is usually due to the brain being supplied with too hot blood, causing impulses to be sent to the glands, which increase their secretion, so reducing the temperature. They may be caused to secrete by emotions, arising in the brain—*e.g.*, the cold sweat of fear.

Having considered the production and the loss of heat, we have now to discuss how it is that these two processes are so balanced that the temperature of the body is neither increased nor decreased—in other words, the "regulation of temperature." Evidently the temperature may be regulated in two ways—(1) by increasing or decreasing the production of heat; (2) by decreasing or increasing its discharge. Nature makes use of both these ways.

As regards the former mode, we obtain a great deal of information from observing the effects of heat and cold on cold and warm-blooded animals respectively. Heat, of course, increases the activity of chemical processes. In the body of a cold-blooded animal exactly the same occurs when it is exposed to heat—*i.e.*, its tissue-changes are accelerated, its discharge of water and carbonic acid is increased, and more energy is set free within it, causing the animal to be more vigorous and lively. Cold, on the contrary, decreases the activity of its vital processes, and makes it torpid and heavy. Exactly the opposite effects are observed in warm-blooded animals. Up to a certain limit heat decreases their vital activity, so diminishing their production of heat, and making them less energetic and lively. Cold increases the activity of their vital processes, causing increased discharge of carbonic acid and water, with greater energy and liveliness, neccessarily accompanied by improved appetite. Everybody must have observed the very different condition of a healthy man as regards energy, appetite, &c., in cold and hot weather respectively.

As regards the second mode of regulation, our knowledge is much more extensive and precise. It is due to the action of a well-defined nervous mechanism, which produces its effects by influencing the circulation. In order to understand its mode of action, and to form an idea of its wonderful delicacy, we must briefly consider the structure of the arteries.

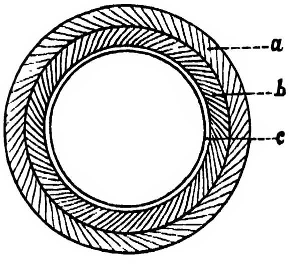

Fig. 3.—Diagrammatic Section of an Artery.
a, Outer Fibrous Coat; *b*, Middle Muscular Coat; *c*, Inner Elastic Coat.

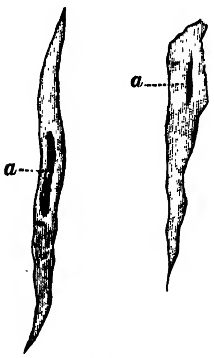

Fig. 4.—Muscular Fibre of an Artery. (*Highly magnified.*)
a a, Nucleus.

A medium-sized artery (Fig. 3) has a wall composed of three coats—an outer one of connective tissue (*a*), a middle one of muscular tissue (*b*), and an inner one of elastic tissue (*c*), lined by flattened cells. The muscular tissue differs in structure from that of the muscles proper, and unlike them it is not under the influence of the will. It is composed of long nucleated cells, which wrap round the artery, and as they are contractile they are able to diminish its calibre (Fig. 4). The inner coat is very elastic, so that a piece of artery will stretch almost like a piece of india-rubber. The muscular coat has small nerves distributed to it, which are called *vasomotor* nerves, and are connected with a part of the central nervous system called the *vasomotor centre*. When the centre is stimulated, it may cause the muscular coat of the arteries to contract, so diminishing their calibre; or it may contract some arteries and dilate others. The mode of action of this mechanism is as follows: When the blood is too warm it so influences the vasomotor centre as to cause dilation of the blood-vessels of the skin, making it flushed and red. At the same time the sweat-glands are excited to increased activity, profuse sweating occurs, accompanied by a general sense of warmth, owing to the quantity of hot blood sent to the skin, and a rapid loss of heat goes on.

If the temperature of the body rose to 50° C. death would ensue; and yet a man can bear with impunity a temperature considerably above 100° C., the boiling point of water, as was proved more than a century ago by two physicians, who stayed for some time in a chamber heated to 127° C., without injury. This is due to the cooling mechanism already described being brought into play. The vasomotor centre can be influenced in various ways, not only by too warm blood. Stimulation of almost any sensory nerve will influence it, and so indirectly the circulation. It is also influenced by emotions, as is exemplified in the well-known phenomenon of blushing. An emotion causes a more or less localised dilation of blood-vessels, usually those of the face, so that an increased supply of warm red blood is sent to it, and the face gets red and hot. When one gets "hot all over" this is due to a similar but more general dilation of the cutaneous arteries.

Alcohol quickly influences the circulation, causing dilation of the cutaneous arteries, so creating an evanescent feeling of warmth, soon followed by a fall of temperature, due to increased loss of heat. This may be the *rationale* of the idea very generally prevalent in the tropics, that brandy and water is "the safest drink." Hence also it follows that the common custom of taking spirits "to keep out the cold" is a mistake; but into the merits of alcohol as a stimulant it is beyond the scope of this paper to enter.

If the skin be cooled its blood-vessels are constricted, and the blood is withdrawn from it into the internal heat-producing organs, so causing a rise of temperature. Heat produces just the opposite effect. This is not due to the vasomotor system, but is simply a local effect.

From all these considerations it is easy to see that the application of external heat and cold, in order respectively to warm or cool the body, defeats its own object; and that, paradoxical as it may appear, the best way to raise the temperature of a healthy, well-fed man is to expose him to cold, whereas exposure to heat will tend to lower his temperature. This explains the well-known fact that the best way to keep warm in cold weather is to take active exercise in the open air, not to be crouching over the fire.

It is only in man that this temperature-regulating function of the skin is so prominent and important. The lower animals are commonly clothed with hair or wool, so that they cannot lose very much heat by their skin, and the respiratory mechanism is made use of in their case in order to keep down the temperature. It has previously been stated that about 20 per cent of the total loss of heat takes place in man by the lungs. When a man has been running, or performing other muscular work, his breathing becomes quickened, so that the loss of heat in warming the expired air and in evaporating the water of respiration is increased. This channel for the discharge of heat is of very subsidiary importance in man, but in the lower mammals it is of great importance. In very hot weather dogs may be observed with their tongues hanging out, and breathing rapidly; their tongues are very vascular, and they in this way expose a large surface to the cooling action of the atmosphere.

The consideration of these various regulating mechanisms enables us to understand how it is that the temperature of a warm-blooded animal is so remarkably constant, under whatever conditions of heat or cold it be placed. They are, however, efficient only up to a certain point, for if a man be exposed to a very low temperature, though he will at first respond to it by increased production and diminished loss of heat, yet finally the intense cold may overpower the nervous mechanism, and death ensue from rapid fall of temperature, the cessation of the vital functions.

A GRAIN OF SAND.

By Professor W. C. Williamson, LL.D., F.R.S., Owens College.

Were any number of persons asked if they could define what sand is, few probably would fail to give an affirmative answer; but in attempting to furnish an exact definition most of those who tried would probably discover that their notions respecting the material in question were more hazy than they had imagined. The term "sand" is, in fact, a vague and comprehensive one, the siliceous material present to the minds of most of those responding to the question being but one of the innumerable varieties of sand that are known to exist, and one that occurs only in very limited amounts, except near recent or ancient lines of coast. Speaking broadly, sand is mineral matter, of any kind, that is in a state of comminution between the condition of gravel and that of mud. The substance to which the term is usually applied in this part of the world doubtless consists of minute siliceous granules, sorted by the prolonged agency of water out of the mixed materials with which its currents have come into contact; but those mixed materials are themselves also the resultants of a complicated series of antecedent agencies, of which the earliest are, and probably will for ever be, unknown to us. When we find sand in the bed of a stream or on the shores of the ocean, we may safely conclude that it has been more immediately derived from the banks of the one or the varied coast-line of the other. So far as size alone is concerned, sand is only one of the smaller of a series of states which include in ascending order gravels and blocks of stone of every degree of magnitude. It is in most cases the product of a long-continued process of washing, or lixivation, like that employed in mining operations to separate the heavy grains of metal from the lighter elements of the ore. The sea-waves beat perseveringly against some mouldering coast-line, upon which they make inroads with varying velocities dependent upon the resistance that the coast is able to offer. Along the low shores that prevail between Flamborough Head and the chalk cliffs of Dover this resistance is, unfortunately for the owners of the neighbouring acres, but too feeble. In such localities the finest particles are usually carried far seaward, to be deposited as mud in the more tranquil depths of the ocean; the coarser sands or gravels being retained nearer the shore, to constitute the beaches and sandbanks that fringe the coast-line. These fringes differ much in character because of variations in the tidal currents that flow over them. In some places we have long stretches of unbroken sand, which continue unaltered day after day, until some change takes place in the transporting power of the tidal wave which sweeps away the sandy carpet, and reveals the floor of coarse gravel upon which it rested, and which it had previously hidden; whilst the next tide may bring back all the vagrant material to its former resting-place. These fluctuations of position, however, must be distinguished from those more radical changes that add to the aggregate amount of the sand.

Nowhere can these changes be better studied than along the coast-line of Eastern Yorkshire. Its conspicuous headlands are proudly uplifted beyond reach of the tidal waves that undermine the foundations upon which they repose. Losing their supports, especially where the crest of the cliff consists of hard arenaceous rocks that rest upon a softer base, vast masses come thundering down, and form a breakwater that gives some protection to the cliff against the unwearied foe that threatens its destruction. Sometimes, as at the foot of the Castle Rock at Scarborough, many of these masses of sandstone are piled up beyond the reach of ordinary tides, but do not escape when north-easterly gales drive the breakers high up the cliff. At a lower level these headlands project their bases seawards—either as flat tide-washed scars, or as reefs of loose, water-worn rocks, draped with dark fringes of olive-coloured seaweeds that are reflected in pools of water of crystalline purity.

These headlands embrace within their outstretched arms the sheltered bays so characteristic of that noble coast, and of which the beaches, left uncovered by each receding tide, are composed of the most varied materials. In some of the retired nooks between the north Bay of Scarborough and Cloughton Wyke we discover beds of gravel so minutely fine as to be but a few degrees removed from the state of "sand." South of Scarborough we have Carnelian Bay, covered with coarser gravels, the hunting ground of numerous visitors in search of the small pebbles to which the bay owes its name. At Filey Bay, on the other hand, the retiring tide reveals long stretches of sand—often flat as a bowling-green and firm as a well-mown lawn, its smooth surface broken only by the fringed crests of the projecting Sabellæ, or by the funnel-shaped depressions, with their contiguous hillocks of sand, that mark the two ends of the tunnelled home of the Lugworm. At other times these sands are left loose and incoherent, especially near the high-water mark; the weary traveller sinking into them almost ankle-deep, and moving almost as far backwards as forwards with each spasmodic attempt at progress.

But such variations are not limited to the Yorkshire coast. There are some coast-lines which retain definite features through long periods. The case of the Chesil Bank, with its permanent and graduated gravels, is well known. The shore at Hastings and St. Leonards displays but little sand. It is chiefly composed of coarse gravel, which, however, would soon be swept eastward were it not for the artificial groynes. On the other hand, the shifting sands which bar the approach to Liverpool require incessant watchfulness, lest the buoys should guide vessels to shipwreck instead of into navigable channels.

It must not, however, be supposed that all these variations in the distribution of sand are confined to the sea-shore. They extend, in some places, into the deeper recesses of the ocean, as might have been expected when we remember that the variations in the mechanical composition of deposits, whether on the coasts or in the deeper seas, are largely due to the influence of currents of water, whose transporting power varies with the rapidity of their motion. It is scarcely needful to add that the river sand, so dear to gardeners and florists, owes its existence to similar, though more local, agencies than those which affect marine accumulations. However straight the course of a tiny brook may be in the first instance, a few detached sods (Fig. 1, *a*), whilst protecting the bank from which they had fallen, would throw the full force of the stream obliquely against the opposite bank (Fig. 1, *b*), which would soon be more deeply cut into, whilst the current of the opposite side, enfeebled by the impediment that deflected it from its direct course, and thereby losing some of its transporting power, would deposit its coarser sands (Fig. 2, *a*) on the protected side; such deposits thus encroaching upon the water as the water encroached on the opposite bank. A bend thus produced, however slight in the first instance, would steadily increase in magnitude, and become a cause of similar action in the opposite direction (Figs. 2, *b*, 3, *b*); hence it would inevitably follow that the meanderings of the brook would steadily increase in number and magnitude (Fig. 3, *a*, *b*, *c*), whilst an interrupted series of sand deposits (Fig. 3, *a*, *d*, *e*), would be formed behind each of its tiny sheltering headlands.*

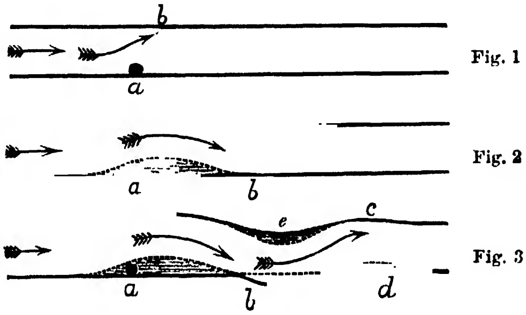

Fig. 1—3.—Diagrams showing how the Course of a Brook gradually becomes altered.

In the cases just spoken of, the free particles of sand are only sifted out from amidst the other friable materials with which more ancient agencies have intermingled them. But in many parts of the sea-coast the sea cliffs consist more or less of sandstones of various degrees of hardness. Formerly incoherent sand-beds, they have become consolidated into hard rock, but are restored to their primæval condition by the constant action of the sea waves that beat against them. In these cases the sand grains added to the sea-coast chiefly consist of minute quartzose particles, such as are commonly understood to characterise sand grains. The entire line of the Yorkshire coast, from Filey Brig to Rockcliffe, furnishes illustrations of these disintegrating agencies. The siliceous grains thus derived are intermingled on that coast with the minute atoms of carnelian, agate, and other objects of volcanic origin, washed out of the boulder-clays of the coast which contain so remarkable an admixture of stones brought by ice action from more northern localities. But on the same coast a quick observer will occasionally detect on the surface of the tide-washed sand thin layers of black particles. Sometimes these consist of fossil carbonaceous atoms of vegetable origin, derived from the plant-bearing sandstones of the coast, or they often tell of disastrous shipwrecks amongst the colliers engaged in carrying the coals of the Tyne and the Wear to more southern parts. But in many instances the black element consists of atoms of magnetic iron, probably derived from the ancient volcanic rocks so abundant in the boulder-clays. One of the amusements of my boyhood was to collect and dry these black sands, and fish out from them, by means of a magnet, the Ferric particles to which the sands owed their dusky hue.

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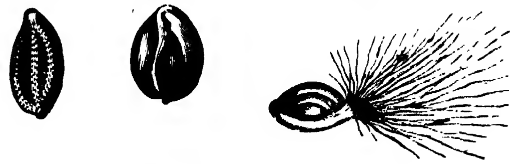
* "Science for All," "Rivers: their Work," Vol. I., p. 208.

In the preceding remarks siliceous sands have chiefly been referred to, but on many coasts local deposits of shell sand are not uncommon. These deposits are very variable both in composition and in amount. A very remarkable one exists at Dog's Bay, in Connemara, which is made up of fragments of the shells, crustaceans, and echinoderms living in the neighbouring seas, intermingled with minute testacea and innumerable Foraminifera, especially Miliolinæ (Figs. 4, 5, and 6) and Truncatulinæ. In this instance we have a calcareous mass that only requires consolidation, by the infiltration of water containing carbonic acid, to convert it into a shelly limestone. In warmer temperate and tropical seas, sands of this organic character are extremely common. They especially abound in Foraminifera, mingled with other elements of organic origin. In the eastern parts of the Mediterranean and on the coasts of the Adriatic, such sands contain an abundance of beautiful Foraminifera (Fig. 7), many of which are closely allied to those constituting chalk (Fig. 8).

Fig 4 Fig. 5 Fig. 6



Figs. 4—6.—Recent Miliolinæ.

Sands from many parts of the Cuban coast are chiefly composed of water-worn particles derived from the neighbouring coral reefs, but they also abound with tropical Foraminifera. Sands which I have obtained from the scanty beaches of the Pacific island of Tonga consist almost wholly of specimens, perfect or fragmentary, of the elegant Foraminiferous Orbitolites, reminding us of the Nummulitic Limestones found in various parts of the world (Fig. 9).

Fig. 7

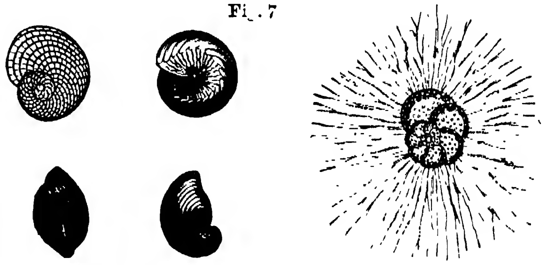


Fig. 7.—Recent Foraminifera.

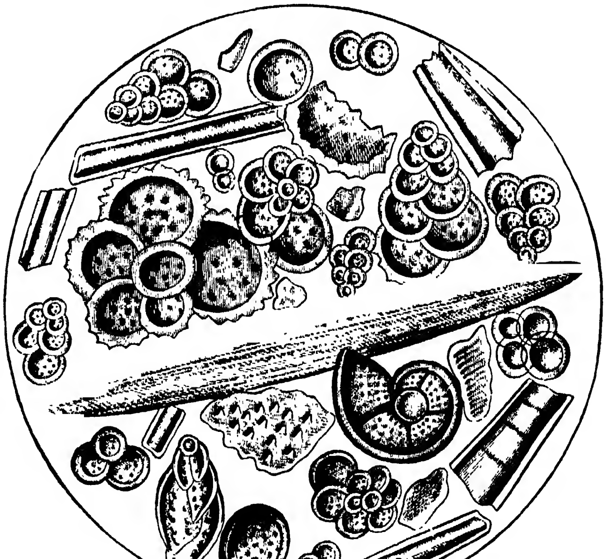


Fig 8.—Foraminifera in the Chalk of Gravesend. (*After Ehrenberg.*)

In marked contrast to the snow-white beaches composed of fragments of these calcareous organisms are the black sands found on the shores of volcanic districts. Sands of this character from the Neapolitan coast consist almost wholly of gravelly particles derived from the ancient lavas that have flowed from the inland craters and reached the sea. At Horta, in the Azores, "the sea-beach has a most peculiar appearance to an eye not accustomed to volcanic shores, being composed of fine volcanic sand, which is absolutely black. The sand is made up of ground-up lava-ejected dust, and is full of crystals of olivine, augite, hornblende, and quartz, with abundance of magnetic iron particles, which cling to a magnet when it is brought near."* But one of the most remarkable sands hitherto discovered has been obtained from the eastern part of the Mediterranean. It consists chiefly of siliceous casts of the chambered interiors of the various Foraminiferous shells that abound in the neighbouring sea. Silica, derived from the sea water, has replaced the soft animal substances that tenanted those chambers, whilst the investing calcareous shells have subsequently disappeared—dissolved out, in all probability, by the action of carbonic acid. Such replacements, in the interiors of shells, of animal substances by silica are a phenomenon with which most geologists are familiar. Similar free silicified casts of Foraminifera can frequently be found in the white chalky Foraminiferous sediments obtained by brushing in water the white surfaces of the hard flints so common in the soft chalk of South-Eastern England.

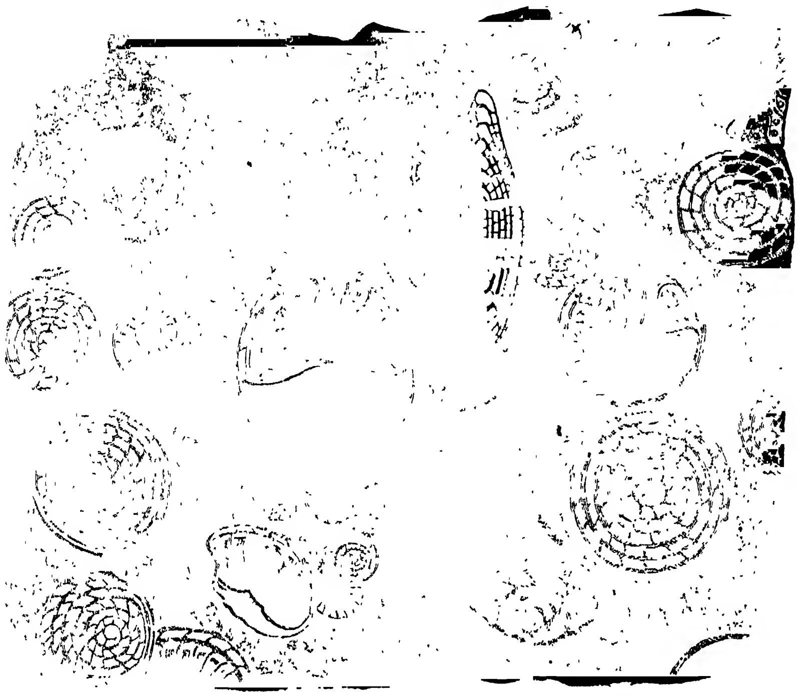


Fig. 9.—Nummulitic Rock from Nousse, in the Landes, showing several species of Foraminifera.

The above remarks suffice to show how varied are the microscopic aspects of sands. Their chemical composition is somewhat more constant—the prevailing ones being either siliceous, calcareous, or an admixture of the two.

We may now regard sand in the light of a rock-builder. It may fairly be inferred that in the first instance all sedimentary materials were derived from the cooling crystalline crust of a heated globe. Hence their origin was virtually volcanic. Their subsequent history has been one involving many changes: now loose sands, then hard rock—water-worn strata of older date providing the materials out of which newer ones were formed. Leaving out of sight for the present the great organic masses of chalk and limestone (Figs. 8 and 9), which have doubtless been formed in deep seas, the shore and shallow water accumulations of sand, whether siliceous or calcareous, evidently contributed much to the formation of the stratified crust of the earth. Many of the Carboniferous sandstones, as well as those Triassic ones which formed the well-trodden feeding-grounds of the Cheirotherium and its companions, were unquestionably shore deposits, which doubtless extended under the shallower seas. Their littoral character exposed them to tidal and other disturbing agencies; hence they are less frequently found in vast masses of uniform composition than is the case with the limestone strata. The shelly sand of Dog's Bay reminds us of the Tertiary Crags of Suffolk, as the calcareous ones of the shores of Tonga and the coral islands of the Pacific do of the Calcaire Grossière of the Paris Basin. The exact processes by which loose and shifting sands like those constituting the sandbanks surrounding our coasts were consolidated into some of our best building-stones is not easily determined; still less so is the origin of the Ferric oxides that bind together the siliceous granules of the Old and New Red Sandstones. Nothing exactly resembling these deposits appears to be forming at the present day, except when some fragment of iron, that has lain long at the bottom of the sea, has become oxydised, and bound the sand or gravel surrounding it into a hard conglomerate. But the case is otherwise with the calcareous sands. We see them undergoing conversion into hard rock in many localities. The celebrated Guadaloupe deposit, in which the fossilised skeletons of human beings have been found, is a well-known example. Sir Wyville Thomson, in his narrative of the voyage of the *Challenger*, and Mr. Moseley, in his admirable volume already quoted, have described similar deposits at Bermuda, where, in some instances, the sand becomes so consolidated as to be used for building fortifications. Then by assisting to silt up the river estuaries and shallower oceanic channels, it becomes a land-maker. Every delta owes its existence to such combinations of sand and mud. But in other cases it acts in an opposite direction. Drifted by the winds, and especially when its friable materials are bound together by plants, it often builds up barriers which resist the encroachments of the ocean upon the land. But whilst fulfilling this conservative function, it too frequently proves to be a treacherous ally of humanity. What it prevents the ocean from doing it does itself. Where the winds blow persistently from the sea, they carry the loose sands steadily over the cultivated land, and spread desolation where all was previously smiling fertility. The Bermudan sands are fearful offenders in this way (Figs. 10, 11); and there is much reason for believing that many of the vast deserts of Africa have been brought into their present state by the eastward movement of the sands of the western coasts. In doing this, the drifted sand alters the flora and fauna of a district. It substitutes one set of plants for those very different ones that previously flourished there; and in changing the plants it changes all the various forms of animal life that depended for existence upon special kinds of vegetation.

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* Moseley: "Notes by a Naturalist on the *Challenger*."

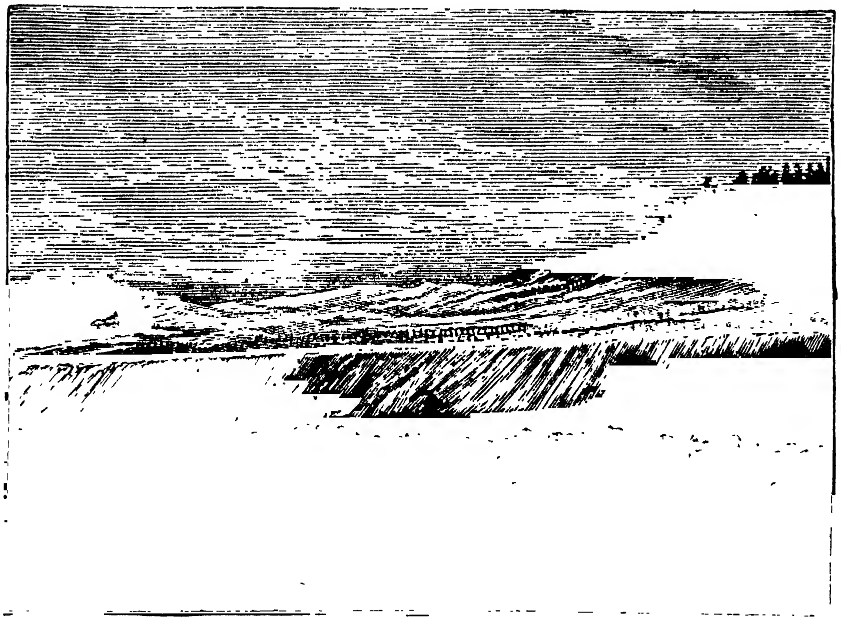

Fig. 10.—"Sand Glacier" overwhelming a garden, Elbow Bay, Bermudas. The Sand has entirely filled up a valley, and is steadily progressing inland in a mass about five-and-twenty feet thick. On its path from the beach it has covered a wood of cedars. (*After Wyville Thomson.*)

In many localities interstratified layers of sand are apt to produce important modifications of the physiognomy of the landscape. When they separate impermeable beds of clay they constitute reservoirs of water, a fact well known to the old Romans. When the beds are inclined, and these waters escape at the hill-sides in the shape of springs, the sand is frequently removed, and the two layers of clay, now brought into contact, only await some unusual downfall of rain for the upper layer to slide over the lower one, producing inconvenient, and sometimes fatal, landslips, as that at Naini Tal on the 18th of September, 1880, when many lives were unfortunately lost. Many of the Diluvial Hills around Scarborough are more or less scarped in consequence of natural operations of this kind. A railway line in process of formation along the coast northwards from Whitby had to be abandoned, owing to disturbances of treacherous foundations brought about by similar causes.

Thus far sand has been viewed only in reference to some of the more important *natural* processes in which it plays a part. But there are many applications of it in which it is subservient to human wants, and not a few in which nature has first taught man how to employ it. Few persons are unacquainted with the ingenious pneumatic machine by means of which sand is exhibited as an engraver.

In this machine a powerful current of air impels dried siliceous sand against a surface of polished glass, from which it removes the polish in a few moments. But when that surface is partially protected by placing upon it thin metallic plates, from which various artistic patterns have been cut out, the sand acts only through the open spaces, leaving the protected portions of the glass in their polished state. But whilst man has but recently employed sand as a sculptor and engraver, nature has done so throughout many long ages. On various parts of the coast, where prevailing winds blow long in given directions and the rocks are sufficiently hard, the latter have been smoothed down by the streams of dry sand perseveringly impelled against them. This is well seen over the Burntisland coast in Fifeshire, in the neighbourhood of the precipices of the Kinghorn. Mr. Buchanan has described* still more striking examples of similar phenomena at Heard Island, in the southern seas. He says that the sand "was being blown with such violence by the then prevailing south-west wind that it was necessary when exposed to it to use some protection for the face. Nowhere have I seen the abrading power of blown sand better exemplified than on the isolated rocks which have rolled down from the heights above and remained fixed in the sandy plain, exposed to the constant strong south-westerly gales, driving the sharp volcanic sand against their sides. In this way they have frequently been cut and dressed as by a mason's chisel." But no one who may be anxious to test the cutting force of wind-driven sands need go so far away as Heard Island to do so. He need only expose his unprotected cheeks for a short time to the pitiless blasts that often sweep over the sands of the Barmouth Estuary, and he will obtain sufficient experience of their power to render all further experimentation needless for his conviction as to what they can do. The use of sand in the manufacture of "sand-paper" is but a modified application of its cutting power.

We learn from the elder Pliny that in his age the Roman millers, lacking good grinding-stones, mixed sand with their lentils to facilitate the grinding of the seeds into flour. In this respect they seem to have been less fortunate than even our savage British ancestors, who manufactured querns or hand-mills out of some of the Carboniferous grits, which grits have received their distinguishing name from the circumstance that the best "millstones" are still manufactured out of them. From the same author we learn that, as now, the Roman marble-cutters used sand when sawing their marbles into slabs and blocks. Though knowing but little of the chemical reasons for their preferences, the Roman workmen were practically familiar with the different qualities of the sand which they employed. Pliny informs us that the best for the purposes of marble-cutting were found to be those obtained from Ethiopia, some from India being held in the next highest degree of estimation. Pliny complains bitterly of "the fraudulent tendencies of our marble-cutters," because they used the river sand of their own neighbourhood instead of the more costly material imported from distant localities.

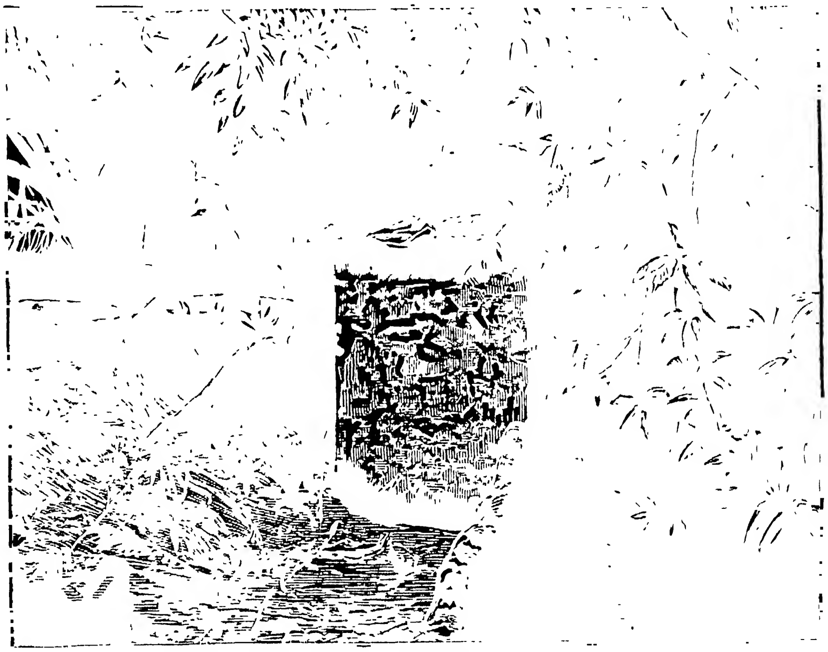

Fig. 11.—Chimney of a Cottage which was buried by the "Sand Glacier," Elbow Bay, Bermudas. (*After Wyville Thomson*)

A still more unusual employment of sand by the ancient Greeks is recorded by Paulus Ægineta, who informs us that sea-sand is desiccative, drying up bodies, especially when heated by the sun; and that when roasted it was used as a dry bath or fomentation in the place of millet or salt, which latter is still not unfrequently employed in a similar way. Then, as is often the case still, men were ignorant of the fact that the heat-retaining power constituted the chief, if not the only, virtue in the materials employed. Saddest of all the ancient uses of sand is that of which the remembrance is perpetuated in our modern use of the term *arena*, signifying any place which is the scene of competitive effort between man and man. Sand was scattered over the floor of the Roman circus to hide the blood shed by the unhappy victims who suffered in response to the cry of the brutalised Roman mob for "panem et circences." Sand is still used in a somewhat similar way in these happier times—a way the memory of which is perpetuated in Goldsmith's exquisite picture of

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* "Proceedings of the Royal Society," No. 170, p. 622.

> "The whitewashed wall, the nicely sanded floor,
> The varnished clock that click'd behind the door."

The introduction of this material as a covering for our floors was a great improvement upon the filthier straw and rushes which formed the substitutes for carpets even in the houses of mediæval royalty. Before the manufacture of "blotting-paper" was brought to such perfection, the sand-box, for drying up freshly-written lines, was the common adjunct of every writing-desk, and even yet may be seen in use for the same purpose in various Continental establishments more frequently than in England. It is not needful here to dwell upon the use of sand in the manufacture of glass, its employment in the construction of moulds in which metal castings are made, or on its admixture with lime for building purposes. All these are sufficiently familiar to every one. It may be remarked, however, that the first and the last of these applications of it were well known to the Romans. In connection with the latter use of it we find Pliny complaining of an abuse not unknown amongst us even now, namely, the too free use of the sand at the expense of the lime, and which, even then, led too frequently to the premature fall of "jerry-built" erections.

One more aspect in which sand may be regarded is that which has swayed the movements of men from an early period in the history of civilisation until now. Assuming that Herodotus was right when he described the ancient Lydians as extracting golden treasures from the sandy, but now goldless, bed of the river Pactolus, we have here a starting point for the long-continued series of gold diggings, which were never carried on more vigorously than during the present century. Lydia has been thrown into the shade by California, Australia, and British Columbia.* The sands of Pactolus and of Aphye grow pale before those of Ballaarat, Carizoo, and the Frazer River. Most of the wealth derived from these rich deposits of drifted material consists of grains of yellow sand.

THE CONNECTING MECHANISM OF THE UNIVERSE.

By William Durham, F.R.S.E.

THE tendency of modern science is towards proving that the visible universe is in *reality* a unity. As we study the stars in their courses we find that they are governed by the same laws which regulate the movements of this little globe of ours. The spectroscope tells us that they are built up of the same materials, and that star differeth from star only in glory, not in kind; that our sun is typical of the whole sparkling host of heaven; and analogy warrants us in believing that these myriad suns will be surrounded by planets suitable for them, and that, in fact, our solar system is but one of a countless host varied in many respects but *essentially* the same.

We are apt, however, to conclude that here the unity ends, and that these systems hang in empty space, and have no physical connection one with another; that the earth even is separated from its central sun and companion planets by a void which cannot be passed over.

There is reason, however, to doubt the correctness of this conclusion, and to believe that the whole visible creation is connected by a real physical mechanism, through which one body influences another in several known ways, and possibly in many ways yet to be discovered. The material of which this mechanism is formed is of so rare a nature that our most refined methods of research fail to detect it. The proof of its presence is therefore entirely inferential, and yet it is strong enough to carry our convictions with it. The following considerations will make this plain.

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* "Nuggets and Quartz," "Science for All," Vol. II., p. 71.

If we arrange several billiard balls in a row and strike the one end of the row smartly the ball at the other end will fly off. We have no difficulty in understanding the action; the force of the blow is conveyed through the whole series by the elasticity of the balls, and the last one, having nothing to stop it, flies off. Again, if we take away the intervening balls and leave only the first and the last of the series, and then, by rolling the first against the last, cause the latter to fly off, we have still no difficulty in understanding the action. In both cases there is a physical connection between the moving body and the body moved. If, however, we have the first and the last balls standing, say twelve inches apart, with nothing connecting them together, and on striking the first we find it to remain perfectly unmoved, while the last, twelve inches away, flies off, we should be profoundly astonished, and the action would be quite incomprehensible to our minds. Our astonishment would not be lessened if we found the same action taking place in a vacuum where there was not even air to convey (by some hitherto unrecognised means) the force of the blow from the one ball to the other. We might put this supposed experiment in another and, for our purpose, a better form. We might place two basins of water a few feet apart in a vacuum, and dropping some small body into one of them cause waves to spread round the centre of disturbance; and, on the supposition we have started with, these waves would appear in the second basin, although there was positively nothing between them by which the force of the wave could be conveyed from the one to the other. Such experiments, if they could be performed, would certainly be very startling and incomprehensible.

Now, surprising as it may seem, this kind of action of one body upon another at a distance has been tacitly assumed and believed by many to exist in nature. Thus, for instance, the attraction of gravity is generally assumed to be of this nature; that it is a force acting somehow from one body to another without any intervening mechanism. From our ignorance of what gravity really is we cannot positively say that it is not such an action, however great may be the difficulty of comprehending it.

There are other actions of one body upon another, however, where our ignorance is not so great, and which we cannot admit as possibly due to action at a distance without a connecting mechanism. Among these actions is radiation of light. The sun is about 90,000,000 of miles distant from us, and separated by what appears absolutely empty space, and yet he sends us his light. Now the question is—How does the light travel across the intervening space? Newton supposed that light was actually substantial matter of a very attenuated nature, which was propelled with prodigious velocity from his surface, and travelled outwards as a cannon ball would. On this supposition there is no difficulty in understanding how the light reaches us. When, however, further researches showed that light could not be regarded as material, but that it was only a peculiar kind of wave-like motion or vibration, the difficulty of understanding how such a motion crossed the supposed absolutely empty space between the sun and the earth was as great as our difficulty with the waves passing from the one basin of water to the other, when there was absolutely nothing between them to convey the motion. We really have no idea of what force is apart from matter, and cannot conceive what form the motion would take after leaving the sun and before it reached the earth if there was no matter of any kind to move in the intervening space.

What we have said in regard to light applies equally to heat and other rays, and also with some modifications to electric and magnetic actions. We are driven, therefore, to the conclusion that there must be some material medium stretching, at any rate, through all *visible* space. This medium, or ether, as it is called, is, as we have before remarked, of an exceedingly rare nature, so much so that it does not appear to offer the slightest resistance to the course of the heavenly bodies in the way of abating their speed in time. One comet has, however, given indications of such a resistance as the ether would give, but with this exception, no heavenly body seems to be influenced by it in this way. This, perhaps, may be accounted for if we imagine the ether to circulate somewhat in the manner of a vortex, in the same direction as the heavenly bodies move, for of course in this case the friction would be greatly lessened, and quite inappreciable in the course of the time during which observations have been made.

Having established the necessity for the existence of this ether, we shall endeavour to find out as much as we can as to its nature and use in various directions. It has been shown * that it is probably more of the nature of a solid than of a gas. This is all we can gather from its action in conveying light across illimitable space. We must look in other directions for further information regarding it. It sometimes happens in scientific investigations that very obscure subjects throw light on one another, and it is so in this case. Electricity has long been a puzzle to scientific men as to what it really is. Some believing it to be two fluids, and others only one, and others again that it is not a fluid at all; and the supporters of each theory had very plausible arguments to advance in its favour—but of late years, by bringing these two obscure things together—namely, electricity and the ether, the late Professor Clerk Maxwell has thrown considerable light on both. Electricity is one of those forces which, at first sight, seem to act at a distance: thus, we know if a body charged with electricity is brought near to another the latter is influenced in a well-known manner, although the two bodies never touch, and nothing passes between them so far as can be seen. Magnetism also behaves in a similar manner. Faraday, however, in his splendid researches on these subjects, showed that the action at a distance is not at all a likely explanation of the phenomena, and that from the electrified body, or magnet, lines of force could be traced in all directions, and he concluded that there must be some medium through which these forces acted. What he meant by lines of force can be very well seen by sprinkling some iron-filings on a sheet of paper, and placing a magnet below the paper, when the filings will immediately arrange themselves in an exceedingly regular and instructive manner; the lines spreading out in all directions are the lines of force, for there the iron-filings are forced to take a particular direction (Vol. I., pp. 182, 183). Taking up this idea of a medium through which electricity acted, and assuming that the electric medium and the light medium, or ether, were the same, Clerk Maxwell set himself to inquire what sort of action in that medium would account for the electric and magnetic phenomena observed. It would be out of place to give his investigations here, but the result he arrived at was that a particular state of stress or strain in the medium, propagated through it at a certain definite rate, would account for all the observed facts. Now an ordinary state of stress can be readily understood—a bent bow, a tightened rope, or a tightly wound up spring are all in a state of stress; they are all held in some position or shape which is not their usual or normal one. According to this view, then, electric and magnetic actions are strictly mechanical, and the medium therefore through which they act must be of a nature capable of sustaining this mechanical stress. Further, if we take a closed insulated vessel, and introduce into its interior a small sphere charged with electricity in the usual manner, we shall find, on examination of the exterior of the outer vessel, that it is charged, by what is called induction, with electricity exactly similar in quality and quantity to that which we have introduced into its interior by means of the charged sphere. Now this shows that electricity, whatever it is, acts exactly like an incompressible fluid; as much of it is forced through the sides of the vessel as we put into its interior. This is analogous to the well-known experiment of filling a metallic sphere completely with water and then distorting the sphere out of shape by a blow, whereby its capacity is lessened and water is forced through the pores of the metal, and it seems to sweat. If we forced extra water into the sphere instead of distorting its shape the same result would follow, as much water would be forced through the pores as we forced into the sphere, supposing water to be quite incompressible, which, however, it is not.

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* "Science for All," Vol. III. p. 314.

Electricity, then, behaves in this experiment as an almost incompressible fluid. If, therefore, the phenomena of electricity be due to stress in a medium, that medium must be almost incompressible. Regarding the nature of this stress in a medium, Faraday and Clerk Maxwell showed that supposing A and B (Fig. 1) to be electrified bodies, and the connecting lines of force, there would then be a tension everywhere along these lines, and also a pressure at right angles to them, as shown by the arrows. This will be understood if we imagine a column of jelly standing on a plate, and we press it down with our finger, there will be pressure between our finger and the plate, and also pressure on the sides of the jelly, tending to press them outwards, as in Fig. 2, where the arrows indicate the directions of pressure, and the dotted lines the shape the jelly tends to take.

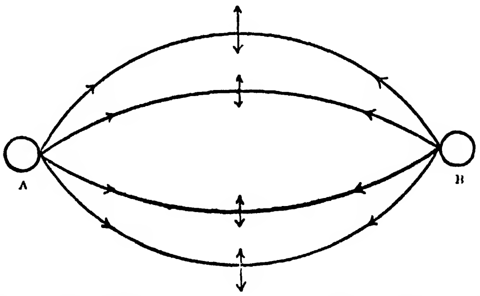

Fig. 1.—Illustrating Faraday's and Clerk Maxwell's Views of Stress in a Medium.

It has been more than once explained in this work that electricity and magnetism are very closely connected. We know from experiment that if a current circulates round a metallic ring, the front of that ring acts like one pole of a magnet, and the back acts like the other, and a magnet is supposed to owe its power to multitudes of little currents circulating round its molecules. We may imagine, then, a piece of unmagnetised iron to have circular currents flowing round its molecules in all directions, some with the front turned one way and some another, and thus neutralising each other and preventing any manifestation of magnetic phenomena. When, however, the iron is brought under the influence of an electric current or of a permanent magnet, these small molecular currents are all forced into one direction, their fronts all looking one way, and their backs, of course, the opposite way, when their magnetic properties become at once apparent. As long as this continues the molecular currents are under stress by the action of the outside current, or magnet, and the state of stress is not only in the iron but extends all through the medium between the iron and the current. Suppose a chain cable, with oval links, flung loosely on the ground, the direction of the links would not be all the same; some would have the longer axis one way and some another, and of course the same with the shorter axes. If, however, we forcibly drew apart the ends of the cable till it was tightly stretched, then all the long axes would be in the one direction—viz., that of the pulling force, while the shorter axes would be arranged at right angles to the direction. This is somewhat analogous to the action we have described between the current and the iron, but must not be supposed to describe in any way what takes place in the medium, but only as an assistance in grasping the idea of stress in a medium—namely, that it is a regular mechanical action propagated from one particle of matter to another, and not some occult force acting at a distance. Now, we know that the sun acts in an analogous manner upon the earth; the variations of terrestrial magnetism, for instance, being traced in a great degree to his action. There must, therefore, be a medium between the two by which this action is transmitted. Thus, by the study of light, electricity, and magnetism, we are led to infer the existence of a strictly material connection between the earth and the sun. It is not likely that there should be one medium for light and another for electricity, as nature never makes two ways where one is sufficient, and that the medium is one and the same is still further strengthened by the following considerations. When electricity is propagated in any medium, such as a current in a conducting wire, there is always the magnetic phenomena round the current. This Clerk Maxwell calls an electro-magnetic disturbance in a medium. Now, this disturbance is propagated at a certain rate, just as light is propagated at so many miles per second, and Clerk Maxwell finds that the rate of electro-magnetic propagation is, within the limits of probable error, equal to the velocity of light.

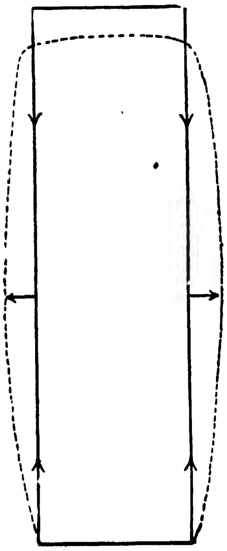

Fig. 2.—Illustrating Faraday's and Clerk Maxwell's Views of Stress in a Medium.

Having thus mechanical energy in the electro-magnetic disturbance travelling at the same rate as light through the medium, Clerk Maxwell concludes that light is in reality an electro-magnetic phenomenon. By the study, then, of these obscure phenomena, we get a considerable amount of information, both as to the functions and the nature of the connecting mechanism, or ether, which pervades all space, so far as light extends, at any rate. In the first place, we understand it must be of an exceedingly rare nature, as planets pass through without perceptible resistance, if we except the one instance of the shortening of the path of a comet. Its rarity, also, is proved by the fact that it passes freely through the pores of transparent bodies, such as glass, &c. Again, though its rarity is so great—so much so that by no known means can we detect it by weighing, nor can we exclude it from the inside of any body, as we would pump air out of a receiver—yet we know, from the nature of light vibrations, it must possess more the nature of a solid than of a gas. From our experiments, also, we see it is highly incompressible, and can sustain great stress, and transmit vibrations and pressures with immense velocity. Probably, therefore, it possesses a jelly-like structure. An attempt has also been made to connect the cause of gravity with the medium, but the difficulty in this question is, that it requires the medium to be of the nature of a gas, with molecules of exceeding minuteness, and moving with immense velocity, which does not agree, as we have seen, with the evidence derived from the study of other phenomena in which, undoubtedly, it plays a principal part. As researches are continued, however, these difficulties may disappear, and this secret of nature also laid open; in which case the last, or nearly the last, stronghold of action at a distance will be destroyed, and the universe will be displayed as one connected arrangement, one part influencing another by a regular mechanism in which there is no break.

Of course, in this inquiry we have been on the very outskirts of science, like pioneers pressing forward into the regions of the unknown, and our conclusions are therefore necessarily imperfect and indefinite; but the prospect opening up to our intellectual vision fills the mind with great and expanded views, and we contemplate with something akin to awe the grandeur and unity of the universe. We find this world is not an isolated speck, floating in the immensity of empty space, but a link in the great unbroken chain of existence, and that star is joined to star, and system to system, and globe to globe, throughout the whole visible universe; but whether it ends there, or stretches into the infinite beyond, we cannot tell,—we may never know. Contemplating these things, we see there is poetry in science little dreamed of, and in the words of the great Humboldt, we experience "a feeling of sadness not unmingled with joy."

THE EARWIG.

By F. Buchanan White, M.D., F.L.S., etc.

Supposing that an inhabitant of one of our busy manufacturing centres—say from the unlovely "Black Country"—were to visit a well-stocked country garden, he would early be attracted by the brilliant hues of the dahlias. He might possibly notice, with even more curiosity, the inverted flower-pot on the top of the stick to which each of the plants was tied. That they are not for ornament is self-evident. However, on lifting one a glimmering of their use would dawn upon his mind, for inside each pot he would notice a number of insects. He would then learn that these insects are the common earwigs, which have nothing to do either with ears or wigs, but whose favourite food is the petals of dahlias, and that being nocturnal in their habits, they find the pot a convenient place in which to hide during the day. The gardener, on the other hand, finds the pot equally convenient, for there he can every morning light upon a number of the enemies of his flowers, and destroy them, without the labour of having to search the plant for each individually.

Most of us are, I imagine, acquainted with the chief features of the external aspect of the common earwig. Its long, narrow, somewhat flattish body, terminated by a formidable-looking pair of forceps, is familiar to most people, but how many are there that know that it is provided with a pair of elegantly-shaped wings? Let us, therefore, examine a specimen more closely, first terminating its life by some instantaneous and painless method (Figs. 1, 2).

Like other insects, the earwig has its body divided into three chief parts—each composed of a number of rings, segments, or somites—the head, chest or thorax, and abdomen or hind body.

The head is small, somewhat heart-shaped, and provided on each side with a rather small compound eye, comprised of a number of six-sided facets. There are no simple eyes (ocelli) such as exist in some other insects. In front of the eyes are the rather long antennæ, consisting of—in the common earwig—about fifteen joints. In some other kinds of earwig the antennæ have no less than forty joints. At the apex of the head is the mouth, which is provided with jaws, and is formed very much like that of the cockroach. The head is joined by a short neck to the chest or thorax, which is composed of the usual three rings or segments. Of these the most conspicuous above is the first (or prothorax), the upper surface of which (or pronotum) is somewhat square-shaped. The next two segments are not—in the ordinary state of the insect—visible above, being concealed below the wing-cases. These—which are attached to the second segment—are two short, oblong leathery plates, whose inner edges meet closely, but do not overlap. They are very much shorter than the body, being, in fact, little longer than the first segment of the thorax, and to an uninstructed eye look like a solid part of the body. If, however, we take a pin, and insert it gently under the wing-case, either

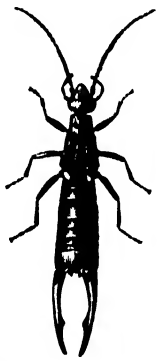

Fig. 1.—Giant Earwig (*Forficula* [illegible]) with

between the two or from behind, we shall find that the wing-case is attached only by its outer anterior corner, and serves as a protection to the wings. These are attached to the third ring of the thorax, and from their beautiful structure are the most interesting part of the external anatomy of the earwig (Fig 2).

Each wing forms rather more than the fourth part of a circle, and in comparison with the size of the insect is of rather considerable magnitude. In fact, when we look at the small space in which, when folded up, the wing has to be packed, we cannot avoid wondering how it can be all stowed away. This is accomplished as follows:—The greater part of the wing—indeed, all except a patch on the front margin—consists of a fine transparent membrane, strengthened by radiating veins. The patch on the front margin is of a leathery nature, and is not covered, when the wings are folded, by the wing-case. This leathery patch is situated about one-third of the length of the wing from the base, and from its apex a series of veins radiate. The radiating veins are thickened about the middle, and beyond the thickening are connected by a transverse vein, which runs round the wing. When the wing is to be packed up, it is first folded longitudinally by the radiating veins being brought together in the fashion of the ribs of a fan. It is then folded back upon itself at the place where the radiating veins are thickened, and a second transverse fold is made at the apex of the leathery patch near the base, and the whole is then tucked away under the wing-case, leaving only the little leathery bit protruding. It may be imagined that an earwig cannot fold and unfold its wings in the simple manner that most other insects do, and as a matter of fact it has to use its abdomen to assist in the operation.

To the under side of the thorax are attached the six legs, a pair on each segment. Each leg is composed of the five usual parts: coxa, trochanter, femur or thigh, tibia, and tarsus; the latter has three joints, the apical joint being provided with claws. As the earwig is a good walker and runner, its legs are strong, and the three pairs are of nearly equal size.

The third great division of the body is the abdomen or hind body—a part which in this insect presents several remarkable features. In the first place, as it is for the most part unprotected above by the wing-cases or wings, the upper surface is of the same hard horny consistence as the under. In the second place, it is remarkable for the large pair of forceps with which its extremity is armed, and which are said to be used, in addition to their being weapons of offence and defence, to assist in folding and unfolding the wings. The forceps vary in size, but are larger and more formidable in the male. Finally, the number of segments of which the abdomen is composed *seems* to differ in the sexes, but only because they are curiously modified. In the male there are nine evident segments, which with the three composing the thorax and the one allotted to the head make up the thirteen segments of which the body of an insect is theoretically composed, but which are rarely seen in the perfect condition. In the female only seven segments are visible above, the seventh and eighth being hidden under the sixth, while below only six are conspicuous, the last three being concealed by the sixth.

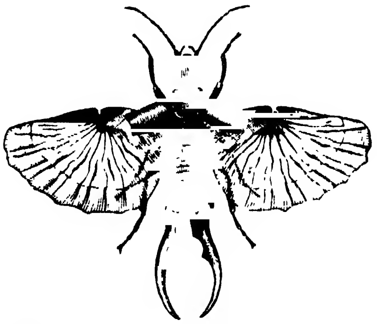

Fig. 2.—Common Earwig (*Forficula auricularia*) with wings expanded.

In its internal anatomy the earwig does not differ very much from the cockroach, recently described. The alimentary canal is, on the whole, less complicated; the salivary glands (sometimes, as in the common earwig, wanting) are not provided with salivary receptacles, and the pyloric *cœca* are also absent. For the breathing system there are ten spiracles on each side, three in the chest and seven in the abdomen, those in the chest being small and much concealed. The first two pairs of thoracic spiracles may be found near the base of the legs, while the third pair lie under and are concealed by the wings.

For a long time entomologists were in doubt in what order of insects to place the earwig. The great Linnæus classed them amongst the Coleoptera, or beetles, and his example was followed by others. Fabricius and others thought that they more properly belonged to the order of the cockroaches, or Orthoptera, where they remained till Kirby instituted a special order—the Dermaptera—for their reception. As the name Dermaptera had already been applied to some other insects, Westwood proposed the name Euplexoptera (from the Greek *eu*, well; *plexo*, I fold; and *pteron*, wing), referring to the structure of the wings. Nowadays they are usually referred to the cockroach and cricket order (Orthoptera), from which they chiefly differ in the peculiar structure of their wings.

Like other insects, earwigs reproduce their kind by means of eggs. These are laid in holes in the ground, or under stones, or in damp places; and, unlike most other insects, which after laying their eggs leave them to take care of themselves, the mother earwig watches over them, collecting them if accidentally scattered, and moving them about from place to place in order that they may obtain the moisture necessary for their well-being. Some observers even go the length of asserting that she incubates the eggs after the manner of a hen, but this seems doubtful. The eggs are laid in April (and probably at other times also), and hatch in May. The young earwigs have the general form of their parents (Figs. 3, 4), but have neither wing-cases nor wings, and their antennæ have only eight joints, instead of fourteen or fifteen. They are also at first whitish in colour, gradually becoming darker. After they are hatched their mother continues to watch over them, gathering them together under her, just as a hen gathers her chickens, and remaining for hours brooding over them. It has been noticed that when, probably worn out with old age, her work having been accomplished, and her offspring being old enough to take care of themselves, she dies, the young ones devour her dead body, as they also do the corpses of any of their brothers or sisters.

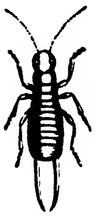
Fig. 3.—Larva of Earwig.

The young earwigs, like other insects, change their skins several times, as they grow too big for their old integuments. How often they moult is uncertain, but after several moults the antennæ get more joints, the wing-cases and the rudiments of the wings appear, and they finally become like their parents in every respect, and, having thus become adult, cease to increase in size or to change their skins. Had entomologists in the time of Linnæus duly studied all this, they would not have placed the earwig amongst the beetles, which, as we have seen in a former paper, undergo a complete metamorphosis, going through the stages of egg, maggot, pupa, and perfect insect, in which each stage is unlike every other. The earwig, it is true, goes through the same stages, but after the egg state the changes are gradual, and not marked by such abrupt alterations in the form, and the metamorphosis is consequently said to be incomplete.

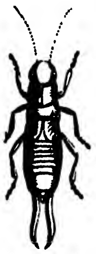
Fig 4.—Pupa of Earwig

Earwigs, though they are not devoid of certain good qualities, must be reckoned as destructive insects, doing much harm in gardens by the injury they cause to flowers and fruit. Sometimes they multiply to such an extent that they become a plague, but this is rare. Could we credit old stories, we might believe that, not content with injuring man's property, they even attack himself, as they are supposed to enter the ears of sleeping persons and penetrate the brain. This story, which has apparently no foundation in fact, has existed in all times and in all countries, as the various names applied to the earwig show. Hence we have the Latin name *Auricularia*, the English *Earwig*, French *Perce-Oreille* (derived, however, according to a recent writer, from the forceps of the earwig resembling the instruments used for piercing the ears for the insertion of ear-rings), German *Ohren Wurm*, Swedish *Ören-Metel*, &c. That earwigs may occasionally enter the ear of a person sleeping on the ground may be true, but they would probably be glad to get out again as fast as they could, and at any rate the drum of the ear would effectually prevent them going very far. Amongst the good qualities of earwigs, apart from the exhibition in so lowly an insect of much maternal affection, is the fact that they occasionally prey upon other injurious insects, such as species of thrips, the maggots of the wheat-midge, and other caterpillars. They themselves are preyed upon by various parasites, including an ichneumon fly, and species of lower organism such as *Filaria* and *Gregarina*. As for the best means of getting rid of earwigs in gardens, the old-fashioned method of suspending flower-pots, screws of paper, old boots, lobster-claws, &c., seems still to be the best. When caught, the insects should be crushed; it is no use putting them into water unless it is boiling, for they swim well.

The earwig, whose structure and history have been sketched above, is the common one (Fig. 5) of this country, the *Forficula auricularia* of naturalists, the name *Forficula* having been given in allusion to the forceps with which it is provided, and *auricularia* being the name used by Latin authors. In Britain there are several other kinds of earwigs, some larger and some smaller than the common garden one, but these, except one—*Forficula minor*, the smallest of all the European earwigs—are rather rare. The largest of the European species (*Forficula gigantea*), not twice the size of the common one, lives among stones on the sea-shore and on the banks of rivers, and feeds on other insects and small invertebrate animals. Such also seem to be the habits of some other species, as they live in places where little or no vegetable food is to be obtained. Earwigs are widely distributed throughout the world, but do not seem ever to attain more than a medium size, and, in fact, have all a great similarity to the species with which we are all too well acquainted. Some, however, have greatly flattened bodies, not much thicker than cardboard, and probably, like other insects of similar flatness, live under the loose bark of trees. It has been mentioned that the common earwig is provided with wings, but these, though well adapted to carry it, seem to be very seldom used, or perhaps, what is more probable, it is not often observed to use them. The small earwig (*Forficula minor*) has, however, often been seen flying. Some species of earwigs have neither wing-cases nor wings, and these, though insects in the perfect or adult condition, resemble the common earwig in its immature stage. Others have wing-cases, but these are soldered together, and there are no wings, or only the rudiments of them.

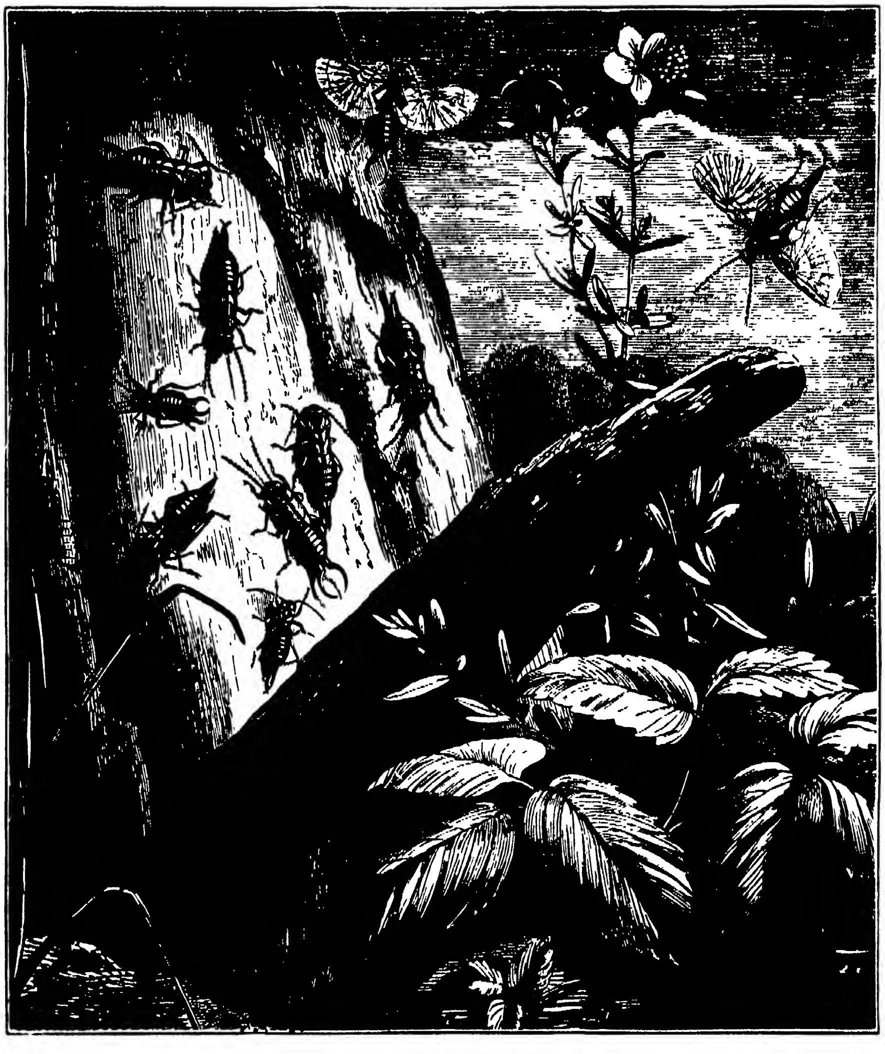

Fig. 5.—Common Earwigs.

In time the earwig family reaches far back, though it falls far short of the cockroach in its antiquity. The earliest earwig occurs in Mesozoic times, a species (*Baseopsis forficulina*), which is unlike any living form, having been found in the Lias of Schambelen, in Switzerland, a formation which belongs to the Jurassic period, a time when reptiles were the dominant class, and that extraordinary animal, the *Archæopteryx macrura*, half bird half reptile, flew through the murky air.

A PIECE OF SERPENTINE.

By Professor T. G. Bonney, D.Sc., F.R.S., F.G.S.

THE late Canon Kingsley showed us what may be learnt of Geology even in the streets of a city. The reader, to his surprise, finds that what previously had seemed dull and uninteresting is turned into a "wayside museum," to use a phrase happily applied by the late Dr. Bryce to a certain rough stone wall in the Island of Arran. In former days, no doubt, each town was to a very large extent constructed with materials derived from its immediate neighbourhood, or readily accessible by water communication. Now, however, that the use of steam has linked together places dissociated by distance on land and wide expanses of sea, materials are gathered from all quarters for the construction or the adornment of the streets. This is especially true of London. To the brick from the adjoining districts, and the stone from Portland, has been added the granite of Cornwall and of Devon, of Aberdeen and of Peterhead, of Shapfell and Dalbeattie. Its streets are paved, not to mention other places, with materials from the Channel Islands and Leicestershire, from Quenast, in Belgium, nay, with basalt from distant Victoria. The railway-station at St. Pancras, with the hotel, is within and without a museum in itself, and many houses and shop-fronts show interesting examples of ornamental stones.

If the London pedestrian is on the look-out as he walks along Piccadilly, he will notice a shop-front a short distance east of Burlington House, which is constructed of a beautiful rock, whose colour varies from a dark to a greyish-green, and from that to shades of red, veined and mottled with bright tints, in which, here and there, on a closer examination, may be seen small flattened crystals of a golden colour and metallic lustre.

This is the rock called serpentine, which, so far as we have been able to ascertain, has only made its appearance of late years in the London streets, and is still not common. Indeed, it cannot be called a common rock anywhere in Britain. In the Lizard district of Cornwall it is abundant enough, but a considerable quantity is valueless for the architect's purposes. There is a little in the north-western part of Wales, and it occurs in some localities in Scotland, the most important being Portsoy, in Banffshire.

But it will be asked, "What is serpentine?" This is the question which we shall endeavour to answer. If you consult books you will find that their authors utter rather an uncertain sound. There is much confusion and ambiguity about the use of the term. One cause of this is that unfortunately the name is applied to both a mineral and a rock. Let us first see to the definition of the mineral. Here, again, it may be that the term applies rather to a group than a single mineral; but, without discussing this question, we may say that it is a mineral, sometimes fibrous, sometimes compact, of moderate hardness, of a slightly greasy lustre and feeling: colour generally some shade of green: composed of about 43½ per cent. of silica, 43½ per cent. of magnesia, and 13 per cent. of water. Talc, soapstone, French chalk, and meerschaum have a somewhat similar composition, with a difference in the quantities of the constituents.

The rock consists chiefly of the above mineral, but contains more or less of others. Among these the most frequent are magnetite, or the black oxide, and hematite, or the red oxide of iron, augite, and the golden-looking mineral already mentioned, which is a variety of enstatite called bronzite—the first two, as may be supposed, have an important effect upon the colour. The rock can be scratched with moderate ease by a knife, breaks with rather curved and sometimes slightly splintery surfaces, has little lustre but a rather waxy appearance, and a slightly greasy or soapy feeling to the hand. The rock on analysis is found to contain about 38½ per cent. of silica, 38½ per cent. of magnesia, 8 per cent. of the iron oxides, less than 2 per cent. of lime and the same of alumina, 12 per cent. of water, and small quantities of other substances. These constituents are, of course, somewhat variable; there may be a little more of one and less of another, but, as will be at once observed, the chief difference between the composition of the mineral and of the rock serpentine is due to the presence of the iron oxides—the most important of the colouring matters to which the rock owes its beauty—and of some adventitious minerals.

We have thus defined our rock so far as can be done from the hand specimen, and have entered into these details because of the vagueness with which the term has been employed. Many rocks differing greatly in chemical composition, intimate structure, and in their relation to other rocks, have been called serpentine. We, however, wish to restrict the term to that particular species of rock of which the Lizard serpentine forms an excellent type. We proceed next to consider its history. A rock composed as above, with so large a quantity of water in chemical combination, can hardly be other than a metamorphic rock; but then comes the question, What was it prior to the alteration—sedimentary or igneous; and if the latter, what name should we have given it could we have seen it before the change? To show what vague ideas have been entertained on this subject, the following statement concerning serpentine from an important text-book will suffice:—"In some cases its transmutation from other rocks is very evident, as, for instance, from gabbro at Siebenlehn, near Freiberg; from dykes of granite traversing serpentine rocks near Böhrigen and Waldheim, in Saxony, where the main serpentine rock itself is not improbably a transmuted granulite; from chlorite-schist at Zell . . . and from gneiss (or probably an eclogite rock in the gneiss) at Zoblitz, in the Erzgebirge."[*] Now a typical granite has about the following composition: silica 72, alumina 16, iron oxides $1\frac{1}{2}$, lime $1\frac{1}{2}$, magnesia $\frac{1}{2}$, potash $5\frac{1}{2}$, soda $2\frac{1}{2}$, water 1·0. It is hardly possible to imagine a greater divergency of composition, and the transmutation required is almost as great as any that was professed by the alchemists of old.

Let us then go to the Lizard and see what evidence we can get in the field. We observe there that the serpentine occurs in enormous masses—extending over not less than a dozen square miles of surface, and in cliff sections more than a hundred feet high. It is clearly no mere exceptional and local product, like those cases of mineral change called pseudomorphism, or like the alterations connected with certain mineral veins. It would be as reasonable to say that basalt was a transmutation product from granite, or *vice versâ*. In this Cornish district, however, there are two rocks frequently associated with the serpentine; these are gabbro[†] and varieties of a rock called hornblende schist. It has here been suggested that the serpentine might be the result of alteration of either or both of these. This notion is less unreasonable than the other, for the composition of both is nearer to that of serpentine, though still with considerable difference. Further, the latter rock is variable in composition, and is generally distinctly bedded, while the serpentine is massive, homogeneous, jointed more like an igneous rock, and yet different from the gabbro. If, however, we examine the magnificent coast sections from the Lizard Head (a mass of hornblende schist) to Mullion Cove on the west, and to Coverack Cove on the east coast, we shall obtain distinct evidence that the serpentine has all the characters of a rock that is of igneous origin, that it is intrusive in the different schists, and has itself been broken into by the gabbro. Here and there we find a junction between the serpentine and the hornblendic schist, where the former has thrust itself into the latter exactly, as a felstone, or basalt, or any other igneous rock would behave (Fig 1); sometimes also it encloses great blocks of the schist, which it has evidently torn off from the main mass on its upward progress. In a similar way we find the gabbro cutting through, thrusting veins into, and including blocks of the serpentine (though of smaller size, the rock being more brittle) (Fig. 2). Here, in every example that we examine along the coast—and there are dozens—there is not the slightest evidence to be found of a passage of the serpentine into the adjacent rock. The boundary is as sharp and distinct as if the two

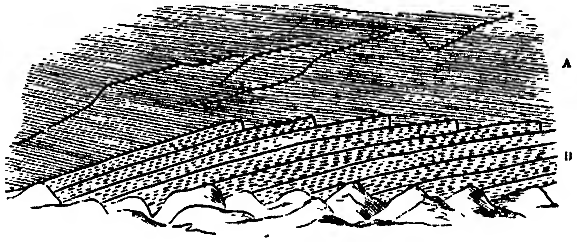

Fig. 1.—Junction of Serpentine (A) and Hornblende Schist (B) on the Shore of the bay north of the Balk, Lizard.

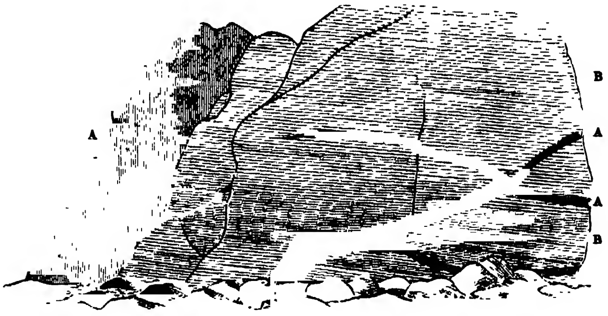

Fig. 2.—Veins of Gabbro (A) in Serpentine (B), north side of Karak Clews, Lizard.

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[*] "Cotta Rocks Classified and Described," translated by P. H Lawrence, 1878.

[†] An igneous rock composed of a plagioclasen felspar and diallage, with commonly some olivine.

surfaces were welded together; you may put the point of your knife on the exact junction, and examine it in a thin section under the microscope.

When we bring this instrument to aid our investigations we shall find that we are enabled to decide not only that the rock is certainly of igneous origin, but also what is has been formerly. It would obviously be most readily formed from a rock consisting mainly of silica, magnesia, and iron. We should, therefore, look for its representative in a non-aluminous or felsparless group of rocks; and such a group there is—though a not very abundant and till lately not very well known one—that called the Olivine Rocks, or Peridotites. Now, at first, when we place a slice of Lizard serpentine beneath the microscope, we can say no more than that it is like nothing else that we have ever seen, omitting one or two distinct minerals occurring here and there. We observe a nearly transparent field, with a slightly veined or "marbled" structure, more or less tinged with green or red, and with scattered grains of iron peroxide. On applying the polarising apparatus and crossing the prisms, we find that a good deal of the field becomes dark, but is traversed by wavy strings, or an irregular reticulation of a pale-tinted finely fibrous mineral. Examination of numerous slides will, however, reveal to us in them a certain resemblance to the structure of the mineral olivine, and at last we shall obtain a specimen where several grains of this mineral still remain unaltered, dotted about the slide (Fig. 3). We then betake ourselves to the examination of the Peridotites, and select for especial investigation one called Lherzolite,* because it is known to contain enstatite or bronzite and a variety of augite. Specimens of this assume sometimes a slightly serpentinous aspect, and on placing a slice cut from one of these beneath the microscope, we find it traversed by thin strings of serpentine. These run in a root-like fashion about the slide, the process of conversion into serpentine having obviously taken place along the rather irregular cracks which traverse the grains of olivine (Fig. 3). This mineral also frequently occurs in fair-sized grains in the rock called gabbro. If we examine some of these, selecting specimens where the mineral has assumed a serpentinous aspect,† we shall find corroborative evidence. From the same block specimens may be obtained which exhibit the olivine barely changed, partially altered, and in some cases wholly converted into serpentine, showing in the last case the same irregularity of structure as we noted in our first specimen.

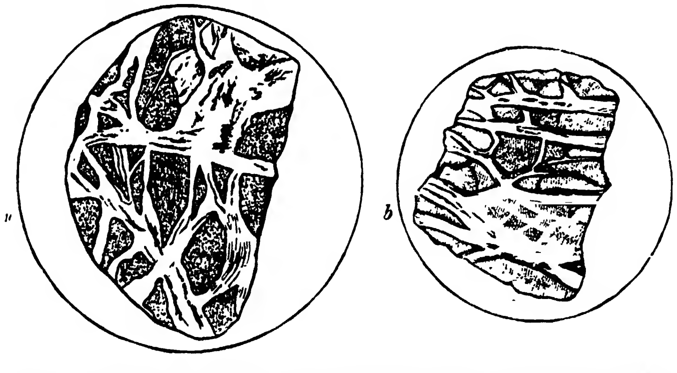

Fig. 3.—Portions of Slides of (a) Serpentine and of (b) Lherzolite seen under the Microscope. The dotted part is unchanged Olivine.

The process of alteration is as follows:—It commences along the larger cracks which traverse the olivine, following in most cases the planes of natural cleavage of the mineral. The first stage is the formation of a layer of fibrous serpentine, with the fibres at right angles to the crack. An irregular reticulation of serpentine strings is thus produced, the meshes being formed of unchanged olivine. The iron, which is a constituent ‡ of that mineral, does not of course enter into the composition of the serpentine, but is oxidised and thrown down in tiny grains or as a clotted dust on the outside of the strings; sometimes, indeed, the net-work looks as if it had been irregularly tarred. The last stage is the conversion of the remaining olivine into serpentine. When this takes place, the non-doubly refracting variety of serpentine seems to be generally formed; the iron is thrown down as a granular clot in the inner part of the grain; and considerable molecular disturbance seems often to take place, destroying the continuity of the net-work previously seen, and giving that irregularity of structure which we have noticed as common in ordinary serpentines. The enstatite also, which is present in the rock, is sometimes more or less changed into a serpentinous mineral.

The chain of evidence then seems complete. Serpentine, using the term as above defined, and thus including all or nearly all those which are employed for decorative purposes, is an altered olivine rock, such as Lherzolite. To this class belong the serpentines of the Lizard, Wales, and

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* The name is from the Lac de Lherz, in the Pyrenees (Ariege), where the rock occurs.

† One of these gabbros, to the eye much resembling a serpentine, found at Coverack Cove, affords excellent instances.

‡ Olivine: 38 to 43 silica, 43 to 51 magnesia, 8 to 18 iron protoxide.—Nicol: "Mineralogy," p. 269.

Scotland—already mentioned; the serpentine of the Rhonda Mountains, in Spain; the beautiful varieties from the Appenines, such as the Verde di Prato, and the rocks of Levanto and Genoa; that from Elba, the Greek Isles, various districts of Germany, and occasional localities in the Alps. Much, however, which in these last mountains now bears the name of serpentine, has no right to it; and probably the above explanation does not apply to the handsome rock obtained in Connemara, which, however, we have not yet had the opportunity of examining in the locality where it occurs.

HOW EARTHQUAKES ARE CAUSED.

By Professor P. Martin Duncan, M.B., F.R.S., F.G.S.

THE trembling and shaking of the earth, the falling of buildings, the opening of the ground in long fissures, and all the attendant horrors of the earthquake, impressed mankind in the early ages with the idea that it was a supernatural occurrence. This is still the belief in most countries where earthquakes are severely felt—countries where the volcanic soil yields easy harvests, where the necessaries of life are few, and where Nature smiles and frowns by turns on the most ignorant and superstitious of mankind. The earthquake was, and is still, considered a direct punishment visited upon the unusually callous. But there was a regularity observed in the results of the earthquake. It was noticed to be restricted to certain parts of the earth and to certain parts of countries, and there was an apparent connection between it and the volcanic eruption. And as knowledge increased, it was discovered that earthquakes were very numerous, and that the notion of one sudden and catastrophic shake of the ground was not consistent with facts, many minor shakes being found preceding and following every great one. Finally, the effects of earthquakes on the sea, in producing waves which travel at a great pace, and on the land in destroying towns by cracking the walls in definite directions, led to the scientific study of the whole subject. The shaking of the earth, which produced the results, was shown to be accompanied by sound, and to be derived from a vibratory and wave-like movement. It was studied, and Mallet laid the foundation of and greatly increased the knowledge of this new science, which took the title of Seismology, from *seismos,* a shake, or an earthquake.

Earthquakes, from their alarming and destructive character, have been recorded in histories; and, as might be expected, the early days of the historical period do not yield so many instances as later times; but the Holy Land, Greece, the Grecian Archipelago, and Italy were evidently much troubled by these catastrophes. Herodotus, Thucydides, Strabo, the two Plinys, and Tacitus are authorities for a series of shocks which occurred from about 550 B.C. to the year A.D. 79, when the great eruption of Vesuvius followed an earthquake. As years rolled on and civilisation extended, the historians of other countries noticed the phenomena, and those of Asia, even as far as remote China, were recorded. Rome and Constantinople appear to have suffered, especially during the fifth century, and indeed the whole of the eastern shores of the Mediterranean, except Egypt. Notices of the occurrence of earthquakes in Spain, France, and Central Germany are given by the chroniclers of events in the latter part of the century, and the Japanese authorities refer to a destructive one in A.D. 600. The records of the seventh and eighth centuries are not so full of earthquakes as those of the sixth, ninth, and tenth, but the records of all Europe came under consideration during the increasing age of the world.

An earthquake was recorded in England as having occurred in 974, a few years after one in Egypt, where a violent shock again occurred in 997. In 1043 and 1048 there were earthquakes of a moderately destructive nature in England, and in March and April, 1076, especially. Every century brought more records, thanks to more exact histories, so that if we were to compare those of the eighteenth and present centuries with those of 500 or 600 years before, it would appear that the unsettled condition and vibrations of the earth's crust were on the increase. It is a matter of more extensive knowledge, and not of the more frequent occurrence of the phenomena. There were, down to thirty years since, at least 6,000 earthquakes recorded, from every known part of the globe and from every ocean, and whilst most of them were in the neighbourhood of active or intermittent volcanoes, others took place in districts which are remote from them, and not a few in places where formerly, and in the last geological ages, there were volcanoes which are now quite extinct. The regions of the Andes, the north of Sicily, and of Naples, close to active volcanoes, are examples of countries pre-eminently subject to shocks; the remoter districts of England and Scotland are comparatively slightly influenced by the cause of the earthquakes; but places like Rome, which are upon old volcanic hills, feel the latent energy beneath them now and then, severely. The earthquake shock and the volcanic eruption, or rather the causes of the trembling of the earth and the explosion and ejection of volcanic materials, are in evident relation, but it is true that whilst an eruption appears to follow and to relieve the earth from earthquakes within a certain distance, there are some regions so remote from volcanic energy that the earth-shake is never recorded in their annals. By placing on a map the places where earthquakes have been recorded, and shading the regions of most frequent occurrence darker than the others, the earthquake tracts of the historic period can be understood. They, of course, run along all the lines of volcanic cones on the earth, and between the nearest; but there are some remarkable exceptions. A map thus shaded, and with blank spaces indicating the countries free from earthquakes, would show how very general are these phenomena (Fig. 1).

It is doubtless true that the earthquake is not recorded by savages, and that there are vast uninhabited tracts on the earth which can yield no histories; and it is important to observe that the blank spots on the map of earthquake distribution relate mainly to Greenland, Continental America north of 60° N. lat., Asia north of the Arctic Circle, and most of Northern Russia in Europe. Africa, except slips to the north, by the Red Sea, and on the extreme south, is a blank space, and so are Australia, except the sea-coast on the east, and South America east of the 65th parallel of west longitude.

The tints denoting regions subject to occasional severe earthquakes will of course follow the lines of eruptive mountains, now more or less in activity, for distant volcanoes burst forth contemporaneously along great distances, and science advances the theory of deeply-seated spaces where the igneous rocks and gases and water are stored under immense pressure. The nearer the volcano the more severely felt will be the earthquake, and intermediate districts will suffer more or less.

An earthquake belt commences in Tierra del Fuego, and is marked along the west coast of South America, Central America, and Mexico. A line runs from the south of what was formerly Russia in America, or Alaska, to Kamtschatka, and thence through Japan. Between these two belts is much of the west coast of the United States, where occasional earthquakes are felt, and from this coast eastwards, occupying the great valley and river basin of the Mississippi and all the States south of the Lakes to the east coast, is a tract never very severely shaken, but subject to continuous small shocks, especially in the centre of the region. An easterly prolongation of the South American belt exists at the equator, and the earthquake belt of the West Indian Islands is continuous with it.

On the other side of the great ocean is a belt, comprising the great islands between Australia and the Asiatic mainland. These often-shaken islands, Java being an example, are extremely volcanic, and it is remarkable that they and one of the great earthquake districts of South America should be placed equatorially. The next belt of much intensity comprises the Italian peninsula and the line of the Alps; and a second is intermediate, and reaches along the flanks of the Himalayas to the Caucasus, and thence by Syria to the Red Sea. The north of Spain mountain district stretches as an earthquake belt to Portugal, Lisbon, and in the Atlantic area to the Azores, Canaries, and Cape de Verd Islands. A region of slight earthquakes extends thence over the Atlantic to the United States.

A northern belt connects Iceland with Scandinavia, and a central European earthquake region is more or less in relation with the Alpine system. Far to the south at the Antipodes there is a belt from New Zealand northwards and southwards, and a branch to the Australian east coast. Finally, the north of Africa, the region of the Atlas, is in a belt which is continuous with that of the volcanic Atlantic Islands. There are probably no spots on the earth where the earthquake shock is not felt, but those mentioned feel it decidedly and sometimes severely. On studying an earthquake map (Fig. 1), it becomes evident that the severest shocks are along lines of volcanic cones and along the flanks of the nearest mountains, amongst which the Himalayas, Alps, Appenines, Pyrenees, Caucasus, Atlas, Californian coast line, and their extensions, are conspicuous examples. The older mountains, such as those of Canada, Scandinavia, Scotland, and Wales, are never greatly influenced by the shock. With regard to the vast surface of the earth covered by ocean, it can only be said that sea waves are produced on a grand scale now and then, without any notice of land earthquake occurring. Probably there is not much earthquake of a submarine origin, and when the sea is affected, it is usually from the results of the shock commencing on dry land and being diffused beneath the sea floor.

There are some of the earthquake tracts—those in the volcanic regions of South America and the islands of Java and Japan, for instance—where the shocks are so frequent, some being very slight and others great, that no relation between the seasons and the phenomena can be made out. Elsewhere it appears that there are two marked periods in every century (calculating for the last three hundred years) when the earthquakes are more numerous and intense, and one occurs in the middle and the other at the end of that lapse of time. The shocks of the greatest intensity are in the middle period, but it must be understood that in the intermediate time, when there are fewer earthquakes, this does not relate to their intensity. A great and most destructive shock may occur irrespectively of time. Usually a great intensity of earthquake action commences rather suddenly, but it does not subside with the same rapidity, for slight shocks occur one after the other, and occupy some time before the ordinary state of things returns. There is some reason to believe that at least one great earthquake, extending over more than 1,000 miles, occurs every eight months, and that at least two hundred, and probably very many more, earthquakes of different intensities occur in the year. Very naturally inquiry has been made regarding the relation of their frequency to the seasons. In the northern hemisphere there are fewest earthquakes in the summer, and the time of least subterranean action is, according to Robert Mallet, in May, June, and July, and the greatest activity is shown in December and January, so that the preponderance of what is called seismic energy, the power to shake, is in the winter. Again, Perrey and Mallet show that between December 11th and 31st, or in what is termed the winter solstice, and between March 10th and 30th, or the vernal equinox, there are the greatest number of earthquakes; the periods of earth repose are at the summer solstice and autumnal equinox. These curious results of many observations are as interesting as those which show that there is a correspondence between the pressure of the atmosphere and earthquake phenomena, the "high glass" produced by increased atmospheric pressure being accompanied by earthquake phenomena. But Mallet suggests that there may be no connection between the pressure of the air and the origin of the earthquake, and he notices that the local increase of atmospheric pressure in one locality and its diminution in a neighbouring one may produce volcanic action, which is in direct relation to the earthquake. The researches of Perrey rather tend to show that when the moon is nearest the earth, the earthquake shocks are the severest, and this statement may be of the same value as that regarding the influence of atmospheric pressure. They both relate clearly to the theory of the cause of earthquakes. Some earthquakes are so slight that the shock is not felt over many miles, others are felt far and wide, and all may be classed as great, middle, and slight, according to the distances along which they are felt. Great earthquakes which destroy cities and produce alterations on the surface of the earth (pp. 64, 65, 68) may have an extreme radius of 540 geographical miles, or 9°: that is to say, they circle on all sides from a centre, and the circle when measured across is 18° of the earth's surface, or 1,080 geographical miles. The Lisbon earthquake is an instance of this kind. The mean earthquakes produce much less destruction and shake down places, but rarely cause loss of life, producing little change in natural objects; they have a radius (a line from the presumed centre of disturbance to its remotest part) of 3°, or 180 geographical miles. Finally, the minor earthquakes, which leave few or no results of their shock, extend over some 60 geographical miles, or 1° in radius; such are, for instance, the little Scottish earthquakes at Comrie, in Perthshire.

When an earthquake occurs and its details are recorded carefully, it is said to pass in a certain direction, and the expression is used, "The shock passed" from some direction of the compass to the opposite: from N.E. to S.W., for instance. In some districts where the shocks are moderately frequent and slight, the direction is almost invariably the same, and even in countries where severer shocks are felt, it often happens that they take a definite line of country, passing along mountain chains and along river valleys, and ceasing sometimes abruptly where the nature of the geology of the district changes. Sometimes, however, it happens when the earthquake is severe that it is felt along very different directions, and the movement is from a centre and radiates in all directions. Starting from some spot, the shock is felt on all points of the compass around it, and the shake is carried along mile after mile, spreading, at it were, in broad circles, but ever moving directly forth in lines. The record will then state that the shocks were felt from such a place moving from S. to N., and in the opposite direction, N. to S., and from W. to E., and E. to W., &c. In reality, all earthquakes start from what may be called a centre and radiate in all directions, but the nature of the ground causes the shock to be severely felt in some, and to be stopped or greatly diminished in other directions. Under all circumstances the intensity of the shock is greatest nearest the centre from which it *appears* to start, and it diminishes gradually with space, and is at last not felt. The movement in the earth which constitutes the shock, travels most readily along solid parts of the crust, and is interfered with by softer portions intervening between the denser, or by changes in the nature of rocks. A mountain chain is, of course, a comparatively solid structure, and the continuity of the earth in a valley is usually perfect, hence the shock is carried along them readily. But if the mountain chain ends in a great collection of soft earth, or in low hills of gravel or mud overlooking a plain, the movement is checked there more or less. A deep valley will extinguish the shock. With regard to the sea, it is evident that the great earthquake waves have an origin in the movement of the floor of the ocean, which is carried out in the very movable water. The waves extend in increasing circles from one spot situated deeply, and every particle of the water on the surface which assumes the movement called a wave, moves upwards, forwards, and then more or less downwards and backwards, towards its original position. In fact, the sea is thrown into the same kind of movement, which is infinitely less perceptible on land, in consequence of the comparative immobility of the particles of rocks and earth. But whilst it is evident that the movement begins deep down in the case of the sea, it is not so readily apparent where it starts from on land. In both instances the movement appears to travel on the surface in a radiating manner, and has apparently more or less regular directions. An examination of the cracks and fissures of buildings which had been produced by earthquake shocks showed Mr. Mallet that this surface radiation, this travelling of the shock in certain directions, was not such a simple thing as might be at first imagined, and that really there is not a direct movement from one point to another along the ground. A city or a house destroyed by an earthquake is a terrible scene of desolation, but there is a remarkable order in the disorder produced by the shock. The buildings are split and cracked in certain definite directions; pillars and monuments fall and walls tumble in positions which refer to the path of the earth movement. Some lines of houses may remain intact, whilst others facing another direction may be levelled with the ground. These lines of cracking and directions of falling, indicate that the movement is not simply one passing along the earth, but coming up from a certain distance below the ground. In fact, originating deep in the earth, the movement radiates on all sides, and at last comes to the surface at one place after another in enlarging circles, taking time, and behaving as if the movement were more or less along the surface. A very striking proof of the deep seat of the commencing earthquake shock—that is to say, of the origin of the movement—was given in describing some of the results of the Calabrian earthquake. It was stated that masses of earth were cast upwards, and the pavement stones of some towns were found lying with their lowest sides uppermost, whilst there were well-authenticated instances of the upward casting, to the height of some feet, of loosely-lying structures (p. 71). To cast up a paving-stone some feet, so that on falling it shall turn upside down, can only be done by a force acting from below like a sudden blow; such a force would have a special direction, which would be almost vertical, that is to say, from below directly upwards. The cracks in buildings were often found to be very parallel with each other, as if the force had struck the edifice not sideways along the ground, but from below through the earth, lifting it partly and splitting it across the direction of the force. Now, by taking the direction or lines of the crack, and drawing an imaginary line at right angles to them into the earth, the direction of the shock or movement can be ascertained. This line plunges down very abruptly in some instances, and in others slopes more gently towards the ground. It makes an angle where it enters the earth, which becomes less and less with distance along the earth from the seat of the deeply originating shock, so that sooner or later the force comes so obliquely out of the earth, or rather, is felt so by buildings, &c., that it appears to travel horizontally along the ground.

Mr. Mallet, by examining the direction of the cracks in many ruins in opposite directions of the compass, found that the imaginary lines drawn by him at right angles to them into the earth, tended to approach each other if they were sufficiently pro-

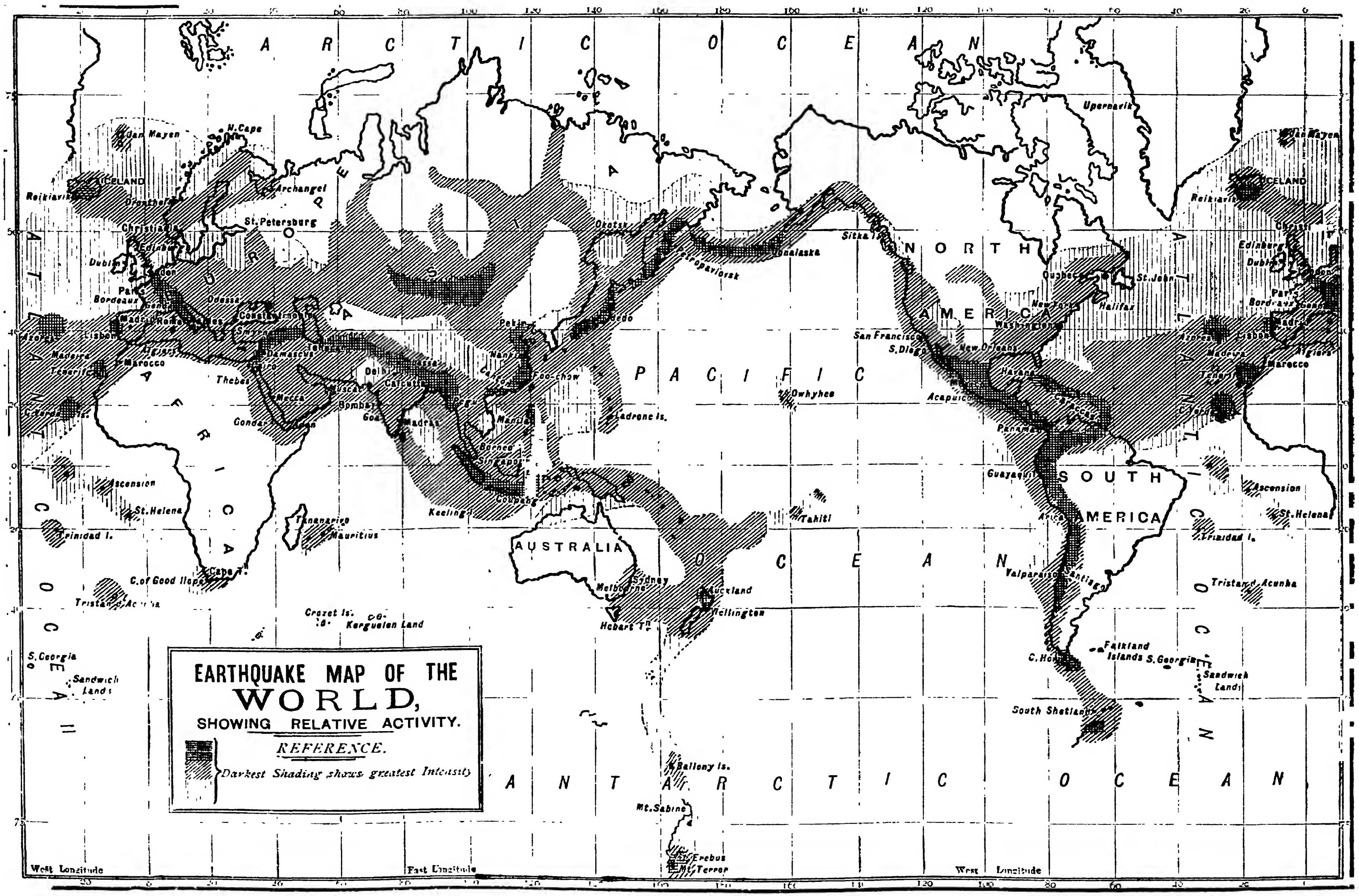
EARTHQUAKE MAP OF THE WORLD,
SHOWING RELATIVE ACTIVITY.
REFERENCE.
Darkest Shading shows greatest Intensity
ARCTIC OCEAN
ATLANTIC OCEAN
PACIFIC OCEAN
ANTARCTIC OCEAN
EUROPE
ASIA
AFRICA
AUSTRALIA
NORTH AMERICA
SOUTH AMERICA
Jan Mayen
ICELAND
Reikiavik
N.Cape
Archangel
St.Petersburg
Drontheim
Christiania
Edinburg
Dublin
London
Paris
Bordeaux
Lisbon
Madrid
Rome
Naples
Algiers
Marocco
Azores
Madeira
Teneriffe
C.Verde
Odessa
Constantinople
Smyrna
Damascus
Teheran
Cairo
Thebes
Mecca
Muscat
Gondar
Aden
Delhi
Calcutta
Bombay
Goa
Madras
Pegu
Pekin
Nankin
Canton
Foo-chow
Manilla
Borneo
Singapore
Java
Coupang
Keeling
Yedo
Okotsk
Petropavlovsk
Onalaska
Sitka
Ladrone Is.
Owhyhee
Tahiti
Sydney
Melbourne
Hobart T.
Auckland
Wellington
Balleny Is.
Mt.Sabine
Mt.Erebus
Mt.Terror
Ascension
St.Helena
Trinidad I.
C.of Good Hope
Cape T.
Tristan d'Acunha
Tananarivo
Mauritius
Crozet Is.
Kerguelen Land
S.Georgia
Sandwich Lands
Upernavik
Quebec
St.John
Halifax
New York
Washington
New Orleans
San Francisco
S.Diego
Acapulco
Havana
Caracas
Panama
Guayaquil
Arica
Valparaiso
Santiago
C.Horn
Falkland Islands
South Shetland
West Longitude
East Longitude

Fig. 1.—Earthquake Map of the World.

longed in a diagram or plan, and that they pointed to the focus, or place of origin, of the earthquake, which was always at a considerable depth. This region of commencing disturbance, Mr. Mallet has explained, may be of considerable size, and from what has been stated in these pages, its connection with underground volcanic phenomena is almost certain. The sudden expansion of intensely heated water in an underground cavity, or explosions caused by chemical changes there, and the injection of lava—that is to say, rock dissolved under great pressure and heat by water—between the strata or layers of the earth, would suddenly press outwards on all sides upon the surrounding dense rocks. These could not move much, in consequence of their being beneath some miles of similar substances, but each particle on receiving the jar or outward momentary thrust would communicate it to that above it, and so on to the surface. At the surface of the ground there are no other dense substances to restrain it, and the motion becomes evident. All along the line of particles there is a movement outwards from the source, and a return in the corresponding and opposite direction. Every spot around the underground cavity has its particles compressed, and as they are more or less elastic there is a return to the original position, except in the instance of the surface rocks. It is just the same kind of movement that may be produced by placing a set of balls in a row in close contact; a gentle and sudden knock on the first, not sufficient to displace it, will act along the whole, but the last ball, not being retained by another beyond, will fly off. This underground movement of the particles on all sides from the focus of the earthquake is said not to be felt in mines, for they are in the midst of rocks which are pressed upon by others, but it becomes evident first of all in the earth directly over the focus. There the blow on the outermost particle will be directly from beneath, and it will, according to the rapidity and intensity of the movement, be shot up in the air, or only lifted up and returned along the same line. The instance given of the capsized paving-stones occurred over what is called the seismic vertical, or in a straight line immediately over the focus. The shock which does the mischief is, of course, first felt on the surface at the shortest distance from the focus or immediately above it; the last feeling of the shock is miles and miles away from this seismic vertical, and that is because the distance between such a locality and the focus is very great, and a great number of particles have to be moved one after the other along a slanting direction. Between the seismic vertical and the remote spot the shocks come up to the surface one after the other with great rapidity. Starting from the focal space, the movement is along a succession of more and more slanting series of particles, and it reaches the surface at the same time in circles around the vertical point over the focus. By drawing a diagram on a map (Fig. 2), of a number of circles becoming larger and larger around a common centre, it will represent the seismic vertical or centre where the shock is first felt, and each circle indicates the points of ground at which the movement was felt emerging simultaneously. The emergence of the movement from below becomes more and more oblique as the circles enlarge, and what is very important, the intensity of the movement diminishes in a corresponding manner. So rapidly do the particles move from below upwards in the successive circles, and so rapidly does each particle return to its place in the same direction, that a wave-like movement is produced along the ground, moving on all sides from the seismic vertical. The rapidity of that movement can of course be measured by comparing clocks at different shaken places on the circles. If a line be drawn through the circles and through the seismic vertical, it will be one along which the wave or apparent along-surface movement will progress from the position of the first shock. Whenever the line cuts a circle to the right or left (or in any opposite directions) of the vertical point, there the shock will be felt simultaneously. The circles are termed seismic circles, and the points of simultaneous shaking or of particle movement are coseismic points.

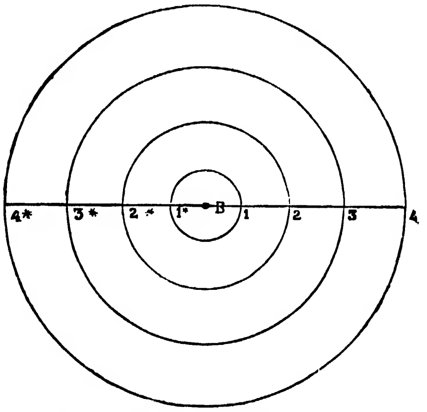

Fig. 2.—Diagram of Seismic Circles.

B, Seismic vertical; 1, 1*, 2, 2*, 3, 3*, 4, 4*, Coseismic points on Seismic Circles.

There is a remarkable difference between the rapidity of the passage of the movement through the earth to the surface and that of the movement along the surface caused by the succession of the former event. The first impetus given by the explosion or expansion within the confined underground space is not carried to the surface with its primary rapidity and strength. The resistance of the rocks is considerable, and the meeting with soft and hard earths interferes. The movement diminishes rapidly towards the surface, and therefore also the force, or the power to do mischief. On the other hand, the succession of surface movements reaching across the circles takes place more rapidly, but it has not a corresponding effect.

If a diagram (Fig. 3) be drawn to illustrate the nature of the movement in the underground rocks from the earthquake focus to the surface, the radiating lines, A1, A2, A3, would represent the direction of the movement. This travels on all sides from A, and the parts of circles drawn show depths where the shock would be felt at the same time—that is to say, the particles would move simultaneously on the lines thus, *c*, *c'*, *d*, *d'*, and so on, as if these were sections of hollow shells placed one over the other. The movement would reach the surface of the seismic vertical (B) first, immediately afterwards it would occur simultaneously at the coseismic points (compare this diagram with the last) 1 and 1', and then at 2 and 2' and 3 and 3'. The particles at B would have returned to their original position before those at 1 began to move at the surface, and these would be moved before those of 2; hence upward and downward movements in succession occur, and this is termed wave-movement, and is the outward manifestation of the inward earthquake movement. The shock or wave will travel from B southwards and northwards simultaneously.

All kinds of secondary effects are produced by this extension of an internal expansive force; the movement may be turned or deflected from its straight path by the presence of solid rocks, and may be stopped by wide faults or divisions in the strata, and moreover sound-waves are produced.

From the nature of the presumed cause of the underground movement, the occurrence of a number of successive shocks is to be expected before quietude recurs. There is every reason to believe that there are deeply seated communications between volcanic regions, and that in the grand, yet almost invisible, movements of the earth's outer parts during the contraction of the whole, as the original heat is lost, spots are relieved of certain amounts of pressure, and great changes occur in the nature of their component rocks. With regard to the depth at which earthquakes commence, Mallet has shown that it varies but is always considerable. By carrying downwards the imaginary lines already alluded to as indicating the paths of emergence of the shock at a number of coseismic points, a rough indication is given of the focus (A in Fig. 3), and it may be deep in itself, wide and extensive, or limited, and at a depth in the earth of from eight to forty miles. Knowing the depth of origin and the rapidity of the shocks on the surface, it is possible to calculate the rate of earthquake movement. Everything indicates that the earthquake is independent of circumstances outside the globe, and that it is an event as necessary and inevitable as the volcanic eruption.

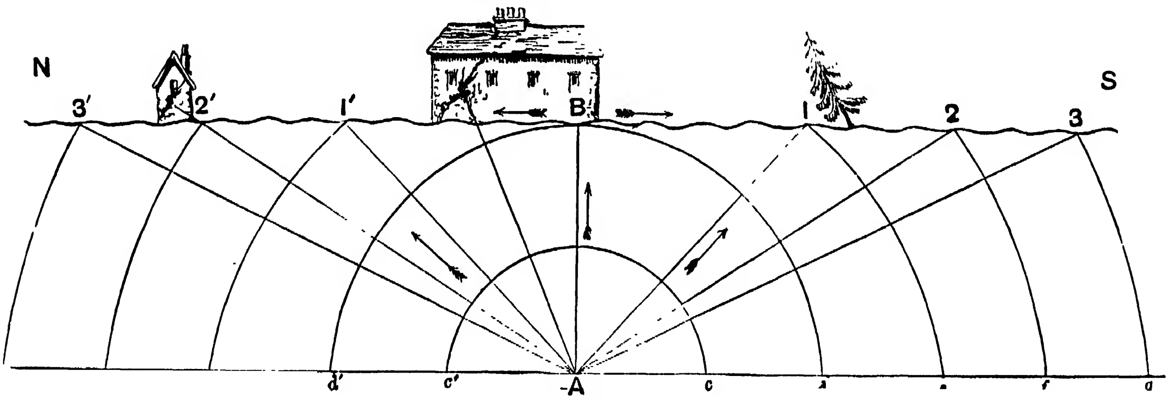

Fig. 3.—Diagram Illustrating Direction of Movement from Earthquake Focus.

THE ORIGIN OF OUR DOMESTICATED ANIMALS.

By Rev. M. G. Watkins, M.A.

APART from the interest naturally attaching to the domestication of the different animals which man has chosen to live with him and minister to his wants, the investigation into the time when he first adopted each, and the manner in which they gradually became tame, is of great importance in tracing the early fortunes of the human race. Civilisation went hand in hand with man's obtaining animals to subdue the ground and supply him with more conveniences of living. Thus a study of the domesticated animals and their origin demands a study of the early inhabitants of Europe, of those primitive cave-dwellers and dwellers in houses supported on piles driven into the lakes, who have been revealed to us by science as the immediate ancestors of historic man. An inquiry, therefore, into the origin of domestic animals compels us to go back to very early days in the world's youth, when Europe was much of it covered with a perpetual ice sheet, and extinct elephants, cave-bears, rhinoceroses, and the like roamed its trackless forests, and reared their young where now stand the proudest capitals of the world. It must be remembered too that Great Britain was during much of this period united to the Continent, and so no one need be surprised at elephants' teeth being dredged up off the Norfolk coast, and at the motley assemblage of wild beasts brought before him by the contents of the hyena's cave at Kent's Hole and other localities. The bones, the tools of stone and bronze, and the like, found in the mud of lakes where were man's dwellings in those prehistoric times, or in the barrows where his tribesmen laid him at rest, will greatly help these investigations. Again, bones and other remains of the domesticated cattle of hundreds of years ago are not unfrequently at the present day found in peat mosses and similar localities, which are useful in these inquiries. Just as the precious translucent jade, which is so eagerly prized both by primitive and civilised man, must have been brought into Europe from China, so the earliest glimpse we can obtain through the dim haze of long distant ages into the history of our domestic animals leads us to think of the tribes of wandering Tartars who at present inhabit the great deserts of Northern and Central Asia, and of the wandering Arabs of southern and warmer tribes, who all adopt the nomad life and take their domestic animals with them from place to place.

These thoughts lead inquirers to a still remoter antiquity, and they see the first travellers from the cradle of the human race finding their way, after the dispersion of mankind, into Europe. The home of primitive man was doubtless somewhere on or near the plateau of Pamir, whence a stream or streams of migration descended upon Hindostan on the one hand and towards Europe on the other. Travelling westwards and south of the Caspian, in all probability, our ancestors made their way through Armenia and Asia Minor, and so over the Bosphorus near Constantinople. It is not difficult to imagine these early folk, with wonder-stricken eyes, lighting upon the sunny regions of Greece and Italy, and at once determining to rest from their toils amidst myrtles and fruitfulness. It were easy for those who pushed still farther west to the pillars of Hercules, and then north till they were confronted by the white cliffs where now stands Dover (supposing that Great Britain had then assumed an insular position), to cross the intervening straits, just as daring barbarian navigators impel their canoes at the present day from their homes in one Polynesian island to another, and as America itself was peopled long ages before Columbus, by means of voluntary exiles or storm-driven refugees carried to its north coasts from Asia by Behring's Strait. Naturally but few domestic cattle would accompany these early pioneers of civilisation; they would gradually domesticate and improve the breeds of such animals as they found useful amongst the indigenous inhabitants of the district. Thus the dog, as we now know it, might well spring from several or many wild types, and the European, or rather Asiatic, sheep be crossed with an American representative of the *Ovidæ.*

Inasmuch as man in a hunting society preceded man as a tiller of the ground, one of the earliest animals which he might be supposed to domesticate would be the dog. Next would come the horse. At least, such would be the order did we trust our own ideas of what would happen in the infancy of civilisation. But how dangerous such *à priori* modes of reasoning are may be seen in this case by calling to mind that in the Homeric poems, long after men had dwelt in settled societies and founded cities, the horse is never employed to help man in hunting. All through the battles before Troy the horse is never ridden by the Greeks. It seems that men had not yet discovered how to ride it, for it is regarded as a beast of burden, useful only for drawing the heroes' chariots. In like manner, elephants were probably never used by the natives in India from which to hunt tigers until the last century, when Europeans showed Orientals their value against a tiger's charge. It is probable, however, that mammals were domesticated before birds. Barnyard fowls, peacocks, and the like are luxuries in the eyes of a race emerging from savagedom. The presumption is, that of animals, the first or one among the first to be tamed was the dog, and to its history, therefore, we shall first address ourselves.

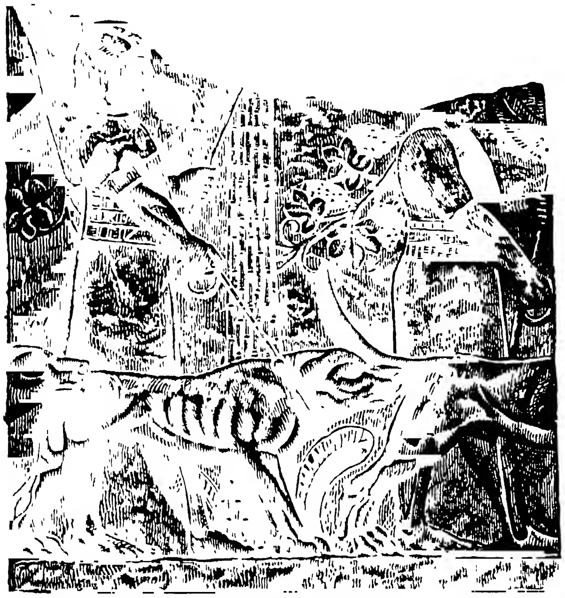

Fig. 1.—Mastiff (*Assyrian*).

The great question with regard to the dog is one which the vast diversity of its breeds naturally suggests: is it descended from one wild ancestor, such as the wolf, or from several? At the earliest known historical period several breeds are found existing, very unlike each other, and closely resembling those which we possess at present.* A glance at any illustrated book on the Assyrian and Egyptian remains will show this (Figs. 1, 2). "But long before the period of any historical record the dog was domesticated in Europe. In the Danish Middens † of the Neolithic or new stone period bones of a canine animal are imbedded," and it has been ingeniously argued by Mr. Darwin that these belonged to a domestic dog, for a very large proportion of the bones of birds preserved in the refuse consists of long bones, which it was found on trial dogs cannot devour. The North American Indian dogs at the present day are like North American wolves; Eskimo dogs too resemble the Arctic wolves. In Europe many Continental shepherd dogs closely approximate in appearance to the wolf. The wolf must therefore be deemed the parent of the dogs of the West. As for Eastern dogs, they may well have sprung from the jackal, so common in hot countries. In the Scriptures dogs are generally spoken of with loathing and contempt. Much pains have been taken in these investigations by Mr. Darwin, and he considers that several species of wolves and jackals must be regarded as the ancestors of the dog, unless we are to accept Professor Huxley's dubious hypothesis of the dog having, like the horse, a still more remote ancestry, which must be sought for in the dry bones of tertiary rocks.

Curiously enough, the habit of barking, which is almost universal with domesticated dogs, does not characterise a single species of the family in a wild state. It is said too that when dogs relapse into a savage state they lose their habit of barking. Climate, again, appears to modify the forms and disposition of dogs. It is for this reason that English hounds when sent out to India rapidly

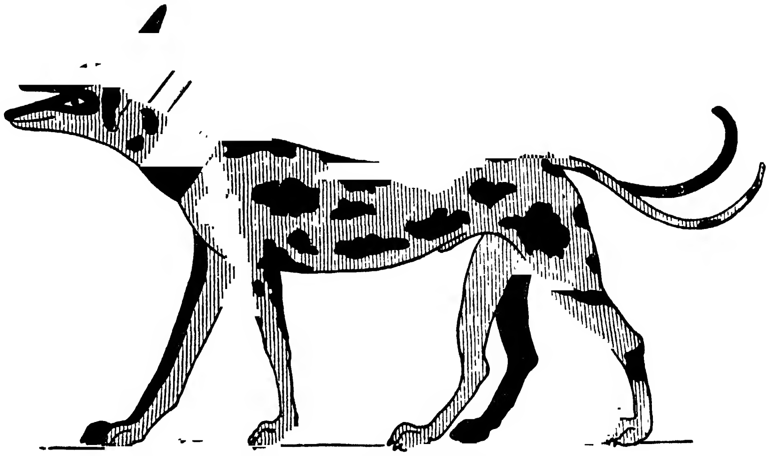

Fig. 2.—Greyhounds (*Egyptian*).

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* Darwin: "The Variation of Animals and Plants under Domestication," Vol. I., p. 16.

† "History out of Refuse Heaps:" "Science for All," Vol. II., p. 102

decline both in bodily constitution and characteristics, while bulldogs lose their pluck and ferocity after two or three generations, and even their underhung jaws. It is curious too how long the dog retains the habits which tell of his wild ancestry. Thus, however well and regularly fed he may be, he often buries, like the fox, any superfluous food; and he never lies down deliberately on the hearth-rug without first turning round and round, as if to trample down sufficient grass to form a bed, just as his far-away ancestors used to do in their native forests.

It has long been known that our domestic cats are not sprung from the wild cat indigenous to these islands, and yet found in the north of Scotland, but from some Eastern stock. The wild cat, indeed, does breed frequently with the shepherds' cats in the Highlands, and St. John remarked on the tendency which the progeny have to assume the characteristic grey and stripes of the wild variety. Cats were early domesticated in the East, as is proved by their mummies found in Egypt. Some have fancied from the very name Puss (*quasi* "Perse") that they came to us from Persia. These Egyptian feline mummies (Fig. 3) belong to three distinct species of cats, of which two are still found both wild and domesticated in parts of Egypt. We do not possess so many breeds of the cat as of the dog, but different types of it exist in different countries. Thus the Manx cats are tailless. In the Malay Archipelago the cats have short tails about half the ordinary length, often with a sort of knot at the end. In several countries the cat has run wild. In New Zealand it then assumes the streaky grey appearance of the cats belonging to the Highland shepherds. The story of Dick Whittington also seems to point to the foreign origin of the cat, while the singular and excessive penalty attached to killing the king's cat by the ancient Welsh laws strengthens the inference that it was highly valued as a precious animal.

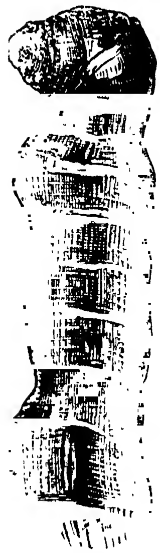

Fig. 3.—Mummy of Egyptian Cat.

The origin of the horse is lost in antiquity* (Fig. 4). Remains of this animal in a domesticated condition have been found in the Swiss lake-dwellings belonging to the Neolithic period. It can withstand great cold, but becomes stunted in islands and on mountains. Neptune produced the horse from the earth by striking it with his trident, said the Greek myth; this looks as if that animal had been transported to Greece by sea. No truly wild horse is at present known to exist; the wild horses of the East are commonly supposed to be sprung from escaped animals, and those in America to be descendants of the horses brought over by the Spanish conquerors, the bones of the original horses of the country in a remote geological age being found in a fossil state. The Normandy farm-horses and those which draw the London drays exemplify the power of careful breeding in improving this animal, for horse-shoes, supposed to be Roman, have been found in the west of England which must have belonged to horses not much larger than our Dartmoor ponies.

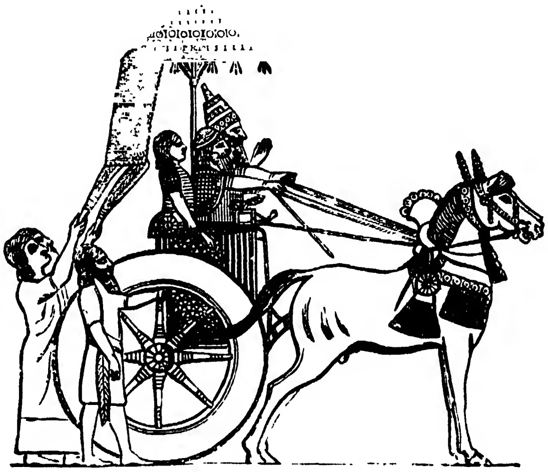

Fig 4.—King's Chariot (*Assyrian*).

As for the donkey, there is no doubt of his having sprung from the wild ass still found in Abyssinia (Fig. 5). The donkey too varies greatly in size and appearance. In Western India, where it is used as a beast of burden, it is not much larger than a Newfoundland dog, "being generally not more than from twenty to thirty inches high."

Coming now to pigs: two parents of all the European pigs are described, one the wild boar, the other a Chinese porcine variety. The wild boar has a very wide range. It became extinct in England only in recent times. Sir T. Cumberworth, a Lincolnshire knight, when making his will in 1450, leaves his "bor sper" to a friend as naturally as might a captain quartered in Bengal, and the wild boar is found in all the intervening countries.

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* See Houghton: "Natural History of the Ancients" (1879), pp. 85-92.

Pigs descended from it were kept by the Swiss lake-dwellers. The Chinese are particularly careful of their pigs, and will not even suffer them to walk from place to place. Few animals vary so much in appearance according to their different breeds. In the central islands of the Pacific Ocean a singular breed is described of small size, hump-backed, with a very long head, short ears turned backwards, and a bushy tail not more than two inches long. The Thersites of pigs must surely be sought in this breed. Tails, however, are appendages with which pigs can easily dispense. We knew a horse which bit the tail off every pig which haunted the fold-yard in which he was kept, and they were none the worse for the mutilation, being able "to roll their prurient skin" in mud, and so do without the organ which is so useful to cows and horses for driving off flies. There is much more difference between a well-bred Berkshire pig and a wild boar than between the wild horse and a modern race-horse. Occasionally solid-hoofed swine are found. Some pigs, more especially those of Normandy and Ireland, exhibit curious tassel-like appendages, which hang from the corners of the jaws. What their use is or whence derived it is impossible to say.

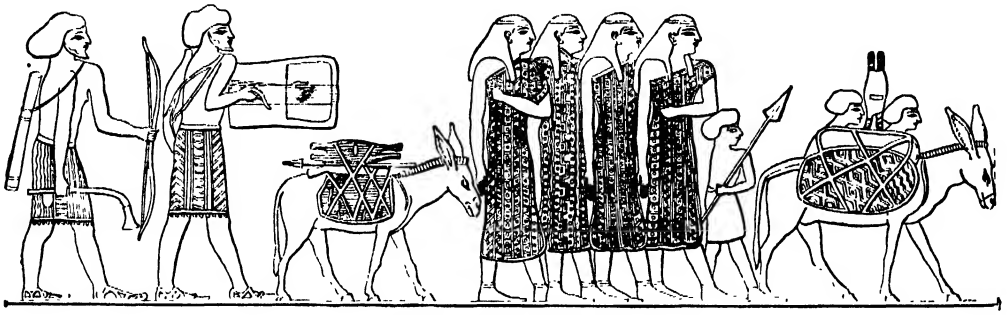

Fig. 5. - Asses (Egyptian).

Just as our dogs and pigs are the descendants of more than one wild form, so cattle fall under two great divisions: the humped kind, inhabiting tropical countries, and the common non-humped cattle. The humped cattle may be seen domesticated at least 2,000 years before Christ on the Egyptian monuments. They have many different characters at present from the ordinary breeds. They grunt rather than bellow, "seldom seek shade, and never go into the water and there stand knee-deep like the cattle of Europe." They have run wild in parts of India, and can maintain themselves in regions infested by tigers. They are best known to us in the form of the sacred Brahmin bulls which walk about Eastern streets, and which it is the height of impiety to drive away from favourite spots or in any way to molest.

Turning to the humpless breeds, at least nineteen well marked varieties are found in Great Britain alone, only a few of which are identical with those on the Continent. By examining the fossil remains of European cattle, two chief types are found, one of which, of great size and ferocity, existed as a wild animal in Cæsar's time, and could never be tamed even if taken young.* According to some this variety is now found in a half-wild state at Chillingham Castle, Northumberland (Fig. 6). The other kind was of small size, and had a short body, with small horns and fine legs.‡ This was introduced into Great Britain as a domesticated animal at a very early period, and furnished food for the Roman legionaries quartered here. It was also very common in Switzerland during the existence of those races of men who used polished stone weapons, and is probably the variety of which Herodotus speaks which was confined in the Scythian lake-dwellings, and fed on fish caught from a trap-door opening on the lake. The little Welsh and Highland cattle of the present day are believed to have descended from this form of the ox. Another species (*Bos frontosus*), with a high protuberance in its skull, was in all probability the ancestor of the Scottish Lowland black cattle with their high foreheads. All our cattle therefore, it seems, sprang from these two types, the large and the small variety, to which this last is closely allied.

The Park of Chillingham is mentioned in the year 1220. Many will remember Sir Edwin Landseer's fine picture of its cattle, painted not long before he died. These animals are white, with the inside of the ears reddish-brown; the hoofs are black, and the horns white, tipped with black. At certain times they are very dangerous to strangers. Several other British parks either have, or had until lately, the same breed. When oxen escape and become wild on desert islands, it has been noticed that the ears of their descendants almost always turn reddish and their skins white, like these oxen.

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* *Bos primigenius.* See Cæsar, *Bell. Gall.*, VI., 28.

‡ *Bos longifrons*, the small Celtic short-horned ox.

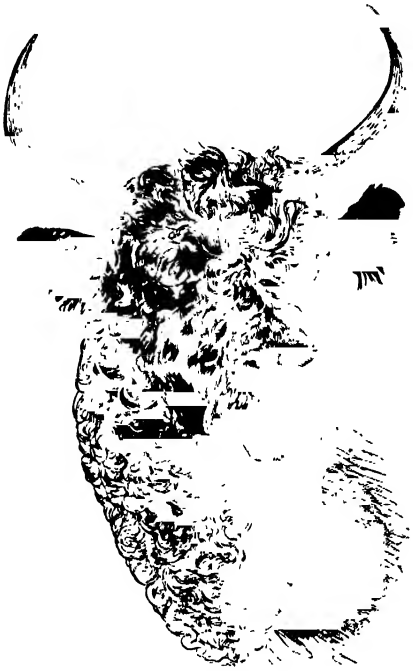

Fig. 6.—Head of Chillingham Bull.
(From a Photograph by the London Stereoscopic Company).

Returning to the British breeds, the chief differences between Shorthorns, Herefords, Alderneys, red Devons, and the like must be familiar to all lovers of country sights. It is very perplexing, however, to assign reasons for these types and their constancy. Each district is wedded to its own variety, and carefully selects the best specimens of it for breeding. Then, again, climate and food doubtless affect these varieties in no inconsiderable degree. In South Africa there are many distinct and equally curious varieties, almost each tribe possessing oxen with different characteristics. Selection, climate, and crossing, as has suited man's caprice, will perhaps account for them all.

Of the more useful domestic animals, sheep and goats yet remain to be treated. From a very early period sheep have been domesticated. The Swiss lake-dwellings have disclosed remains of a small kind, with thin legs and horns like a goat. This species differs somewhat from any now known. Sheep, like cattle, possess many distinctive features, horns or their absence, longer or shorter fleeces, and the like. Our different English varieties are admirably suited for their own localities, and it is curious that they will not succeed in France. Even in some parts of England it has been found impossible to keep certain kinds of sheep. As for the ancestors of our domestic sheep, it is impracticable to trace them. Authorities differ very considerably on this point. We believe that the Ovis Ammon (or wild sheep) of Chinese Tibet is the parent of our sheep. The Big-horn (or wild American sheep of the Rocky Mountains) is closely allied to this. And in Europe lives a wild sheep much smaller than any of these, known as the "Moufflon," or "Musimon;" it inhabits the highest mountains in Corsica and other islands of the Mediterranean.

"In Switzerland, during the time of the lake-dwellers, the domestic goat was commoner than the sheep, and this very ancient race differs in no respect from that now common in Switzerland."* It has certainly come, like so many other domestic animals, from the mountains of Asia, where a wild goat (*Capra ægagrus*) yet lives. The differences in size, length of horns, &c., among domestic goats are very great, but the animals reverts to wild life with much facility, and has been known in Scotland in a very short time to become as suspicious and fleet of foot on the mountains as a red deer, so that it had to be stalked and shot with a rifle. Indeed, it has there been recommended as a substitute for deer. No really wild goat, however, is found in Europe. The animal came in with the men who first settled on the Continent from Central Asia.

One more quadruped remains: the rabbit, so frequently kept by boys. It is descended, there can be no doubt, from the common wild rabbit, but is much modified by confinement, selection, difference of food, and similar conditions (Fig. 7). Hence come all those monstrous forms of the ears which are termed "lops" and "half lops." The rabbit was early domesticated, and the changes it is capable of undergoing may be estimated from the fact that an English lop-eared rabbit has been exhibited which weighed eighteen pounds, whereas a wild grey rabbit weighs only about three and three-quarter pounds. In 1869 another lop-eared rabbit was shown whose ears measured from the tip of one to the tip of the other 23⅛ inches in length and 5½ inches in breadth. The length of ears in a wild rabbit is 7⅝ inches. When tame rabbits of any colour are set free in Europe they generally revert to the original grey of their ancestors. Most of the larger breeds possess larger heads but lesser brains than do wild rabbits, thus showing that disuse of any special need to exercise the brain results in dwarfing that organ, as it does in so many other cases. But on the other hand the food supplies of the nation are largely increased by the great size to which domesticated rabbits will grow, and of course this is the main object of domesticating them.

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* Darwin: "The Variation of Plants and Animals under Domestication," I., 105.

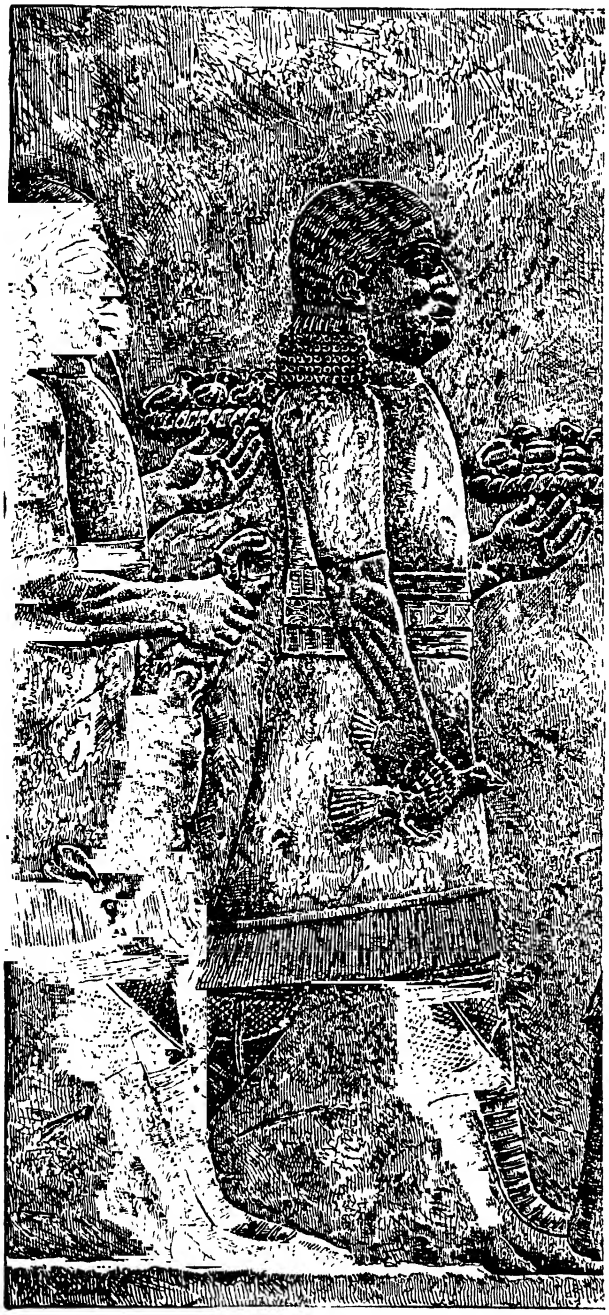

Fig. 7.—Hare and Birds (*Assyrian*).

To turn now to the common birds which have been reduced to subjection by man and taught to stay near his abode. Perhaps pigeons first invite attention. When their variety, curious habits, and fantastic appearance are duly considered, from the fantail, the pouter, the carrier, the Indian tumbler (which tumbles on the ground), the English tumbler (which turns somersaults in the air), and many other singular varieties, it is at first scarcely credible that they should all have sprung from one ancestor, the common blue-rock pigeon of our maritime cliffs; yet so it most certainly is. Careful selection and breeding produced all these wide-spread divergencies. A voluminous literature about the pigeon has sprung up both in European and Oriental languages, and an immense body of observations on it has been accumulated by fanciers, as Mr. Darwin says, "for some 5,000 years." These breeders all find that the white tail-feathers of the wild rock pigeon are continually reappearing in their most careful strains. Nature will maintain her own colour and fashion. From this and other indications there can be little doubt that in the pigeon which darts out of the sea-caves at the approach of a visitor, in the northern parts of our island, the origin of all the varieties may be seen.

Similarly the ancestry of all our domestic fowls may be traced from the jungle-cock of Northern India (*Gallus Bankiva*). Every one is familiar with the surprising differences between black Spanish fowls and Dorkings, Polish fowls with frizzled crests and the diminutive bantam; yet all these are produced, and have been produced, from the same wild fowl of the Indian jungles. Remains of the fowl have been found among pre-historic relics and extinct animals, but it is not named in the Old Testament or figured on the ancient Egyptian monuments. It apparently reached Europe in a domesticated condition somewhere about the sixth century B.C. Julius Cæsar found it in Britain on his arrival. This helps us to form a mental picture of the westward migration of the human race, and we may add a touch to it from a sight which was visible in Sutherlandshire in the summer of 1879. A colony of gipsies was travelling with one cart, which contained several old women sitting comfortably on bundles of straw; kettles and pots were hung underneath the cart, the men walked by the side, and on the rails of the cart sat in great tranquillity, beside the women, five or six fine hens—

the poultry yard of the wandering tribe. But a more sober watcher of the progress of the band might portray to himself that after some such homely fashion did the progenitors both of these people and their poultry travel to us all the weary miles which lie between Europe and the Himalayas.

Our ducks are descended, without a doubt, from the common wild duck, which has a wide geographical range, from North America to Bengal. All country folk are aware that wild and tame ducks will breed together, and that birds so bred from the wild ones are much better for the table than ordinary barn-yard ducks. It is singular that young ducks, even when bred from the eggs of wild birds, often suffer when allowed to go into water at a tender age. We have known one duckling thus put into its native element when about three days old, and suffered to swim. Kindness killed it, and it died of the immersion. This is said, however, to be a well-known difficulty in rearing young ducks. On the other hand, in a wild state, they take to the water at once, and that with perfect impunity.

The next inmate of the poultry yard which calls for attention is the goose. It is manifestly sprung from the common wild goose (*Anser ferus*), which is often and easily tamed at present. The goose was domesticated in Homer's time (Fig. 8), and was kept in the Capitol at Rome as being a bird sacred to Juno. It once saved the city under critical circumstances, as all will remember. As the goose arrives at a goodly size and flavour by nature, domestication has not been put under requisition to produce many varieties, so that this bird has been singularly little changed from the earliest date of its being kept by man. The peacock comes from the jungles of India, and is another bird which has scarcely varied under domestication, except that white or piebald specimens are not uncommon, just as pheasants vary at times. Perhaps the plumage of our tame peacock is rather thicker than that of the wild bird, but no other differences between the two can be discovered. "Whether," wrote Mr. Darwin, "our birds are descended from those introduced into Europe in the time of Alexander, or have been subsequently imported, is doubtful."

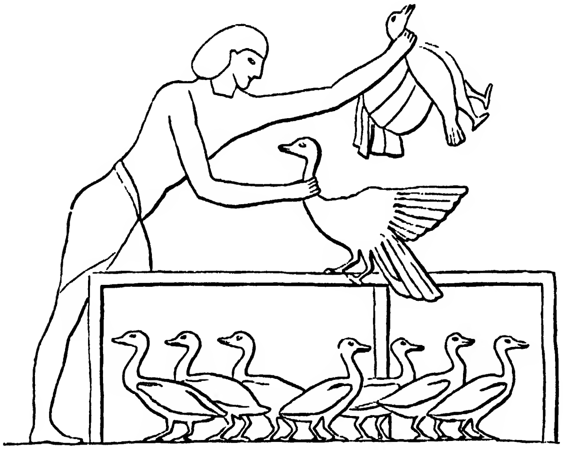
Fig. 8.—Geese (*Egyptian*).

The turkey is, of course, a misnomer. It is descended from two parent forms, the Mexican variety and the wild turkey of North America. These latter birds have been frequently kept in England during recent years. The guinea fowl is another curious misnomer. It inhabits extremely arid districts in Eastern Africa, and has hardly varied at all under domestication, except that the plumage becomes either paler or darker in colour. The parent bird is the *Numida ptilorhynca.* The guinea fowl even now cannot be reared in a damp climate, and loves to lay its eggs away from home in exposed situations, choosing by preference those facing the east, doubtless from some inherited predilection for its old desert life.

One or two remarks may be made in conclusion, though our space will not admit of canary birds pheasants, gold fish, and other household pets being discussed. The history of our domesticated animals, as we have reviewed it, seems to point out that man tamed for his own purposes, first the dog, next the pig, then the ox. This, too, is Professor Rolleston's view. After the primal gift of these creatures to man, the fact that they have so largely improved under his fostering care shows that the conveniences, and even the luxuries, of life are not grudged to man any more than the necessaries. But this gift does assuredly not authorise any manner of cruelty, neglect, or thoughtless usage of the lower animals. He who is most impressed with the long ancestry of our domestic animals, with the benefits they confer on us, with their engaging habits and beautiful forms, is the least likely to behave cruelly towards them. They demand, in return for the benefits they give us, kindness, humanity, and consideration. As with care animals are capable of improvement by man, so he who acts cruelly towards them, himself retrogrades in the rank of creation—

> "Puts off his generous nature, and to suit
> His manners with his fate, puts on the brute."
>
> *Cowper.*

SEA-ANEMONES.

By Dr. Andrew Wilson, F.R.S.E.

THERE are no animals more flower-like in appearance than the familiar sea-anemones of our coasts. Rooted and fixed to the rocks, they spread their tentacles abroad in the limpid water of the rock-pools like so many beauteous blossoms. The anemone-tank in an aquarium is to all intents and purposes an animated flower-garden. The hues of its contents range from the deep crimson of the "mesembryanthemum"—as naturalists term the common species—to the pure white of the "dianthus;" and tints of green and orange, of purple and violet are not wanting to make such a sight as beautiful as it is interesting. The very names of the "anemones," from that latter term itself, to the "dianthus" and "anthea," are derived from the domain of the botanist. As we see the anemones expanded to the full on their rocky shelves and ledges in the aquarium-tank—or better still, if we visit such an anemone-paradise as the caves and grots of the Devonshire coast exemplify—we cannot wonder that terms of floral kind are rife indeed even in their scientific description. Small wonder is it, therefore, that the poet and naturalist should for once agree in sounding the praises of this fixed race of beings.

It is not so very long ago since the sea-anemones and their kith and kin were esteemed veritable plants. Thereby, however, hangs a tale of some little instruction and interest, and its brief recital will form not merely an introduction to sea-anemone structure, but will indicate certain relationships of these beings to other animals of well-known kind. About the year 1706 a famous French naturalist, the Count de Marsigli, had described in his book on the "Physical History of the Sea" the so-called Red Coral "Plant" of his day. In calling the "Red Coral" a plant, Marsigli was simply following the teaching of his own day, and was declaring a fact apparently in harmony not merely with his own researches, but with the collective wisdom of the ancient world.* Ovid had declared, for example, that the Red Coral was a marine plant, which presented a soft structure so long as it remained in its native waters, but which became hard and stony on exposure to the air. This ancient idea was exploded by naturalists showing that the coral was hard whether in water or in air, but the belief that it was a plant still remained up to Marsigli's day. A branch of Red Coral is truly plant-like. As it is obtained fresh from its native waters in the Mediterranean Sea, it is covered with a soft living flesh, as a tree is covered with its bark; and when this flesh is scrutinised closely, there are seen to exist in its substance little flower-like organisms. Each "flower" of the coral has eight little fringed petals; each is highly sensitive, and withdraws itself into the substance of the soft bark when touched; whilst beneath this soft bark is the hard red coral. A certain pupil of Marsigli's, Peysonnel by name, was in time despatched from Paris to the coasts of the Mediterranean to study the "coral plant." This was in 1726. Peysonnel, proceeding with his investigations, soon came to a conclusion utterly opposed to that of his master. Instead of supporting Marsigli's doctrine that red coral was a plant, Peysonnel declared it to be an animal. The so-called "flowers" of the coral Peysonnel urged were true animals; and he suggested their resemblance to the "petites orties," which term is the familiar French appellation for the sea-anemones themselves. Strange to say, the new fact which Peysonnel had discovered was not merely discredited without inquiry into its merits, but the author himself was subjected to a kind of passive persecution which disgusted him with science and European civilisation alike; and he consequently retired to the West Indies, where he practised as a naval surgeon.

But Peysonnel's work and suggestions bore their fruit in due course. A certain Mr. Trembley, an Englishman resident at Geneva, had meanwhile been experimenting upon the little Hydras of our ponds and ditches. He had been slicing these animals in various ways, with the result of discovering some marvellous facts concerning their history and structure. Led by these researches, the same French *savants* who would not listen to Peysonnel a few years before, began to study the lower forms of animal life anew. The result was singularly discreditable to their former treatment of Peysonnel. For not merely the red coral itself, but a whole host of beings, formerly regarded as plants, were found to be true animals. Peysonnel had therefore the grim satisfaction of living long enough to find his views accepted by those who at first condemned them—and these views and opinions have with little variation remained to represent zoological opinion on such matters to our own day and generation. The sea-anemones themselves were only received as animals about 1710, when Réaumur, who had been one of the first to condemn Peysonnel's views, had shown their true nature. Thus the sea-anemones and corals, as well as many other and allied forms of animal life, became the objects of zoological and not botanical study; although it is noteworthy that the discovery of their animal nature is by no means a far back event, but on the contrary a comparatively recent fact of biology.

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* "Science for All," Vol. III., pp. 1–6.

The appearance of a sea-anemone is at once characteristic and familiar. Rooted by one extremity to its rock, the soft, fleshy, cylindrical body bears at its free or upper extremity a mouth surrounded by numerous feelers or "tentacles," as we may term them. It is in the expanded state, when the body-cavity of the anemone is fully expanded with sea-water, and when the tentacles are fully outspread, that the likeness between the animal and the flower is most apparent. If we but touch the tentacles—or if in some cases the sunlight streaming on the animal is suddenly interrupted—the feelers are quickly withdrawn into the mouth, the fluid of the body-cavity is expelled by the latter orifice, and the animal shrinks up into a conical mass of coloured jelly, as unlike its former elegant aspect as can well be conceived. After an interval, the body will expand, the tentacles will be outspread, and the graceful appearance of the flower will once again be assumed. Hence, from this simple experiment, one fact of anemone existence is perfectly clear, namely, that these animals are sensitive to outward stimuli. Not that such a feature of sensibility is necessarily the exclusive property of animal life; for many plants are as highly sensitive as the anemone;* but it is well to note the sensitiveness of the anemone even at this stage of our inquiries, seeing that we shall have to discuss the question of its nervous belongings later on. Another observation may be hazarded at present, however, namely, that the primary use of this sensitiveness, as in the very lowest animals, is that of enabling them to procure food, and to perform that first and all important duty of life—the function of "nutrition." But for this sensitiveness, the anemone—or indeed any other animal—might as well be a non-living mass. Possessing sensibility, the anemone feels the impact of the luckless crab which has incautiously stumbled against its tentacles. It twines its tentacles, like the fabled locks of the Medusa, around the hapless crustacean, which is engulphed within the mouth, and finally disappears for ever within the body of the captor. There it will be digested; crab-matter will in due course be converted into the tissues of anemone existence; the higher life, as in other spheres of nature, is sacrificed to feed and sustain the lower; and a few dismembered claws or the fragments of a shell rejected from the anemone's mouth as indigestible, will alone serve to remind the observer of the crustacean's fate. As with the lion so with the anemone—life is supported only by nature's seemingly harsh dictum of the sacrifice of other lives in turn.

The general structure of a sea-anemone's body is not a matter which demands a large amount of attention, even from the non-zoological reader, for its due comprehension. Firstly, we may remark that the "tissues" or distinct elements of its body are few and simple. Like man himself, the anemone is a "cellular" animal—that is, its frame is built up of the minute elementary parts called "cells," which combine to form tissues. Man's frame unquestionably exhibits a further complexity, in that the original cell-constitution of his body has been elaborated to form structures called "fibres" of various kinds. But the anemone may claim a remote kinship with even the highest animals, not merely in the facts that its body-elements essentially resemble theirs, and in that it also possesses "fibres" akin to theirs, but also in that at one and an early stage of their existence, the highest animals were not unlike the permanent forms of these "sea flowers."

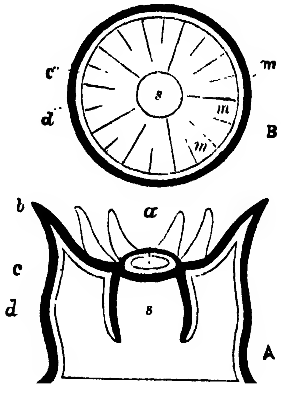

Fig. 1.—Diagram (A) of Structure of Sea-Anemone, and of (B) Cross Section of do.

a, Mouth; *b*, Tentacles; *c*, Endoderm; *d*, Ectoderm; *s*, Stomach-sac; *m*, Mesenteries.

A sea-anemone then, possesses a simple body composed of two layers (Fig. 1). The outer is named the *ectoderm*, and the inner is termed the *endoderm*—these names being the Greek equivalents for "outer skin" and "inner skin." Under the microscope these two layers can be each dissected out into other strata. Thus, the "ectoderm" itself consists of two layers. In the outer, are developed the colours and hues of anemone-bodies, and likewise certain peculiar stinging organs called *cnidæ* or "thread-cells," wherewith the anemone paralyses soft-bodied prey. The inner layer of the "ectoderm" is more delicate than the outer layer, and consists of fibres, analogous to those found beneath man's own skin, and named "connective tissue."

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* "Science for All," Vol. I., p. 179.

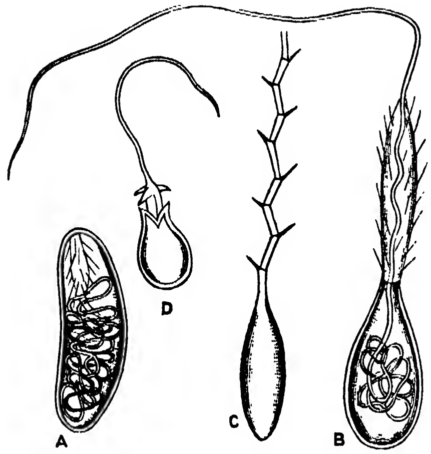

Fig. 2.—Thread Cells. A, Quiescent; B, C, D, Ruptured.

The "thread-cells" first spoken of deserve special mention. Each of these organs is a minute sac or bag containing fluid, and possessing a thread-like filament coiled up in its interior (Fig. 2, A). Under irritation of any kind, such as pressure, the thread-cell ruptures, its fluid escapes, and if the thread itself comes in contact with the delicate tissues of any animal, the latter is stung, paralysed, or may even be killed. Each thread-cell serves once only. When it has been ruptured (Fig. 2, B, C, D), its purpose is fulfilled, and it disappears by absorption, to give place to new cells of like kind. Thus, each of these cells appears in reality to be a miniature poison apparatus, and there are certain animals, nearly related to the sea-anemone, which sting very severely by their aid. The jelly-fishes are the most notable offenders in this respect; and one species of tropical "jelly-fishes"—the *Physalia* or "Portuguese man-of-war"—stings so severely that the effects of contact with its tentacles have been known to persist for many days. The sea-anemones may be freely handled without any symptom of the power of their thread-cells being experienced. But if the tentacles of the larger species be brought in contact with the softer tissues of the body, as, for example, the mucous membrane of the lips, a slight sensation of discomfort may be experienced. The "threads" of these stinging cells in the jelly-fishes differ greatly in their conformation. Very frequently the edges of the thread appear to be developed to form barbs or hooks, adapted probably to secure the adhesion of the thread to the attached body. Thus the anemone possesses means of offence which must unquestionably aid the capture of its prey; and the old adage that "beauty is deceitful" may find in this fact a possibly new application.

The "endoderm" of the anemone is, as already remarked, the inner of the two layers of which its body is composed. In its nature, this inner layer differs widely from the "ectoderm." It is composed of *muscular fibres*, similar in nature and functions to those which form the "flesh" of all other animals, and in virtue of which they execute the ordinary movements of life. Thus we may understand how it is that when touched, a sea-anemone contracts its body so quickly and effectually, since its whole frame is encased within this layer of contractile substance. The fibres of the muscles are disposed both lengthwise and in a circular fashion. In the tentacles and around the mouth the circular fibres are especially developed; and in these regions they therefore act by contracting the mouth and by compressing the tentacles, much in the same way as we close our own mouth by the muscles thereof in the act of whistling. The muscles of the body-walls of the anemone act from above downwards, and have the function of contracting the body, and causing the shrinking so familiar to everyone who has touched one of these animals. Like our own muscles, those of the sea-anemone act under stimulation of various kinds. The irritation of touch, for instance, serves, when propagated through the anemone's frame to produce change and alteration of that body as we have seen—just as, in ourselves, muscular acts, such as the withdrawal of the head from a threatened blow, are the result of stimulation of one kind or another through the nerves. The innermost face of the "endoderm," that is, the aspect which forms the inner surface or lining—of the body, consists of cells, each provided with a fringe of the delicate vibratile filaments called *cilia*. These by their incessant waving, like so many microscopic eyelashes, maintain a continual circulation of the fluids contained inside the body of the animal; and in this way the functions of a heart, in distributing the nourishing fluid through the body, is discharged by these cilia.

No feature of anemone structure, however, is more curious than the disposition of the internal organs (Fig. 3). Not that the animal has much to boast of in the way of internal furnishings, so to speak. On the other hand, as compared with animals which might popularly be deemed low in the created scale, the sea-anemone's structure might be regarded as decidedly primitive. The mouth (Fig. 3, *a*) is placed in the centre of the numerous tentacles (*g*), which again are merely hollow processes of the body itself. Each tentacle is simply a hollow tube of muscular nature, and capable, like the body, of contraction. At its tip, each tentacle is perforated by a minute aperture, and this extremity likewise bears a small sucking disc, the action of which may be felt if we touch a tentacle carefully, when it will adhere momentarily to the finger ere it is withdrawn. When the sea-anemone contracts, the water or fluid of the body escapes by the tips of the tentacles as well as by the mouth; and it is perhaps interesting to note that if an anemone be violently squeezed, the water will also escape through small pores or openings in the body wall. These openings are called "cinclides." They are believed to exist for the emission of thread-cells; but my belief rather leans towards regarding them as chiefly serving the purpose of apertures through which the fluids of the body, rendered effete through excretion or waste-action, are continually escaping.

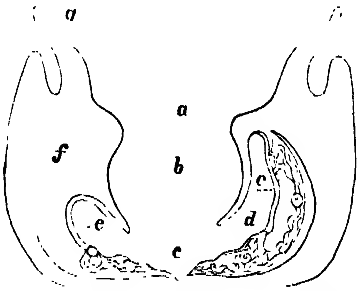

Fig. 3.—Vertical Section of Sea-Anemone, showing Internal Organs.

a, Mouth; *b*, Cavity of Stomach; *c*, Body Cavity; *d*, Intermesenteric Chamber; *e e*, Craspeda; *f*, Mesentery; *g*, Tentacle.

The mouth leads into a wide stomach sac (*b*), but a dissection of the sea-anemone soon reveals the apparently extraordinary fact that this stomach is emphatically like a pocket, with the bottom cut out, and that this bottomless pocket opens freely into the body-cavity (*c*) below. Every reader has seen an "excise" ink-bottle. There, the short inner tube opens into the cavity of the bottle, which forms an outer tube around the inner one. This comparison exactly denotes the structure of the sea-anemone; for, like an animated "excise" ink-bottle, the mouth (*a*) leads into a stomach (*b*), and this latter in turn directly opens into the inside (*c*) of the body. To make such a state of matters clear, let us for a moment consider the nature of the digestive system in a higher animal, such as a fish. There, the digestive system (as in all animals above the sea-anemone and its relations) is practically a tube which runs through the body *without opening into the cavity of the body as in the anemone.* Food received into the mouth of the fish remains within the digestive system and is there digested; waste or innutritious portions being expelled by the terminal part of the digestive canal. If, on the contrary, our description of the anemone be correct, it would seem that food taken into the mouth of the anemone should pass into its stomach, and thence downwards through its open extremity *into the cavity of the body.*

This latter view is theoretically correct; but functionally and in reality, such a catastrophe in the way of futile food-taking appears to be avoided in a simple and ingenious fashion. Digestion is therefore managed in anemone existence thuswise: the food is received into the stomach sac, it is true, but the lower extremity of that sac is capable of being closed by the muscular approximation of its edges, much in the same way as the mouth of a bag is closed by a tape or string being passed round its margin and the ends pulled together. A special muscular development, forming what is known as a *sphincter muscle*, is found at the lower edges of the stomach sac, and serves thus by its action to convert the open stomach into a closed pocket in which the food undergoes digestion. Then, when this latter process is completed, the stomach sac is believed to unclose and thus to transmit its digested contents into the body-cavity, in which they undergo circulation through the agency of the "cilia" with which we have noted the "endoderm" to be provided. It is noteworthy that the process of "nutrition" in the anemone exactly reproduces that which occurs in every other living being. Thus, firstly, a nutritive fluid or *blood* adapted to nourish the body is manufactured or elaborated from the food. Secondly, this fluid is brought in contact by its "circulation" with the tissues it is intended to nourish. Thirdly, these tissues each absorb from this fluid the matter or *pabulum* adapted for sustenance, growth, and repair. And, fourthly, this fluid becoming impure through receiving the effete or waste matters of the anemone's tissues, is duly "excreted"—that is, it is emitted from the body sooner or later, or is purified by the admission of oxygen contained in the water surrounding the body, just as our blood is purified by the oxygen of the air inhaled in breathing. If differences exist between anemone-nourishment and nutrition in ourselves, they are after all differences of degree rather than of kind. And they may be summed up in the remark that, whereas in higher life the nutrient fluid or "blood" has to be conveyed by vessels and by a special circulation, that of the anemone reaches the tissues without the intervention of such a specialised system. In a word, nutrition in higher life is somewhat indirect, and is performed through the medium of heart and vessels; in the anemone it is of the most direct character—the blood, in fact, bathes the tissues it is intended to sustain.

Allusion has been made to the body-cavity of the "sea-anemone," as the space within which the stomach-sac depends. Now this body-cavity (or *somatic cavity*, as it is also named) is interesting from its division into separate rooms or chambers, by the development of a series of plates or partitions which receive the name of *mesenteries* (Fig. 1, *m*). These "mesenteries" run in the long way, or axis, of the body, and therefore parallel with the stomach-sac. Each is a vertical flattened plate (Fig 3, *f*), one (the outer) edge of which springs from the body-wall, whilst the other (or inner) edge attaches it to the stomach-sac. Thus the space between the body-wall and the stomach becomes divided into compartments, called *intermesenteric chambers* (*d*). Below, each mesentery, at the point where it is free from the stomach-sac, curves at first outwards and then inwards, so that it is attached by its lower edge to the floor of the animal's body. Moreover, we may note that certain of the mesenteries are longer than others. Some, for instance (Fig. 1), extend completely between the body-wall and the stomach-sac; these being *primary* mesenteries. Others start from the body-wall, but fall short of reaching the stomach, these being named *secondary mesenteries*; and a third set, starting likewise from the body-wall, but exhibiting a much shorter growth than the "secondary" mesenteries, are named "tertiary" ones.

Thus a cross section of a sea-anemone's body presents us with exactly the form of a wheel (Fig. 1, B). The rim of the wheel is the body-wall; the nave is the stomach-sac; the complete spokes, extending from nave to rim, are primary mesenteries; and the shorter spokes, springing from the rim, but not reaching the nave, correspond to the secondary and tertiary mesenteries. The intermesenteric chambers (Fig. 3, *d*), lined with the ciliated endoderm, present us therefore with a series of compartments through which circulation of the blood must take place; and it is interesting to observe that certain of the skeletons we name "corals" perfectly reproduce in their lime structures the form of the sea-anemone-like animals which made them. For the "corals" are simply cousins of the anemones, and exhibit an essentially similar structure. The mesenteries in their manner of growth follow a special law, whereby the later mesenteries appear between those already formed. In the sea-anemones (as well as in the corals) the mesenteries are developed in definite numbers, or in multiples of these numbers, in each principal group. Thus tentacles and mesenteries in the anemones and their near relations are developed in multiples of five or six. The first cycle of mesenteries, numbering five or six, is developed, and the mesenteries of the second cycle intervene between each pair of the first; those of the third cycle in turn occupying an intermediate position between those already formed. So that if A represents those of the first cycle, B those of the second, and *c* those of the third, their arrangement may be thus tabulated:—

A *c* B *c* A *c* B *c* A etc.

The free edges of the mesenteries are provided with curious cord-like structures, which receive the name of *craspeda* (Fig. 3, *e*), and which, being richly provided with "thread cells," are believed to serve purposes of offence and defence. Possibly, prey swallowed in a living condition will be paralysed or killed by the action of these internal weapons.

That anemones are highly sensitive to touch was a fact elicited at an early stage of our inquiries. We know of many lower animals (such as the Bell-Animalcules) which are sensitive in the absence of nerves; but our sea-anemone is found to possess the beginnings of a nervous system, adapted not merely to provide the animal with the sense of touch, but probably with a broad and generalised sense of vision as well. When we look carefully at that rim or margin of the mouth which lies outside the tentacles of the common sea-anemone of our coasts (*Actinia Mesembryanthemum*) we perceive a series of bright bead-like specks, which, in addition to their shining aspect, exhibit likewise a brilliant coloration. The structure of these colour specks is more complex than might at first sight be imagined. They consist, each, of rudimentary structures, which we only find in the eyes of higher animals. Amongst other belongings, for example, they contain refracting cones and other bodies adapted to modify rays of light; and most notable of all is the observation that beneath each pigment spot is a series of nerve cells, and a nerve mass, or *ganglion*. There is, therefore, no doubt that the sparkling beads around the sea-anemone's mouth are in reality simple organs of vision. These eyes doubtless serve to render the animal highly sensitive to light and darkness, but this statement may be said to be very far from including the idea that "sight," as exercised in higher animals, is possessed at all by the anemones and their kind. The nervous system of these animals, in its other and more general aspects, is chiefly concerned with the reception of sensations, and with the stimulation of the muscular layers of the body. Nerve filaments of rudimentary nature are certainly found in the disc or surface of attachment of the anemones. But the chief difference between such a primitive system of nerves and that of higher animals, appears to consist in the absence in the anemones of well-developed nerve centres, or controlling masses, of which the brain and spinal cord in ourselves, or the nerve ganglia of lower animals (*e.g.*, insects, molluscs, &c.) are good examples.

The structure of a sea-anemone does not comprehend its entire history. The question "How did it grow?" opens up a new vista of inquiry, to which, by way of close to this biography, we may briefly direct attention. Anemone existence, sooner or later, comes to a close, like that of all other living beings; although, indeed, the history of the famous anemone, known to a wide circle of acquaintance as "Granny," shows that anemone life may occasionally attain an age approaching the human "three score and ten." This anemone (now in the Royal Botanic Gardens, Edinburgh) was first obtained from the Frith of Forth by Sir John Dalyell, in 1828, and has given birth to numerous progeny at various periods. But such instances of longevity are probably rare, and as one anemone generation dies away, another generation appears to take the place of the former, and to perpetuate the race in time.

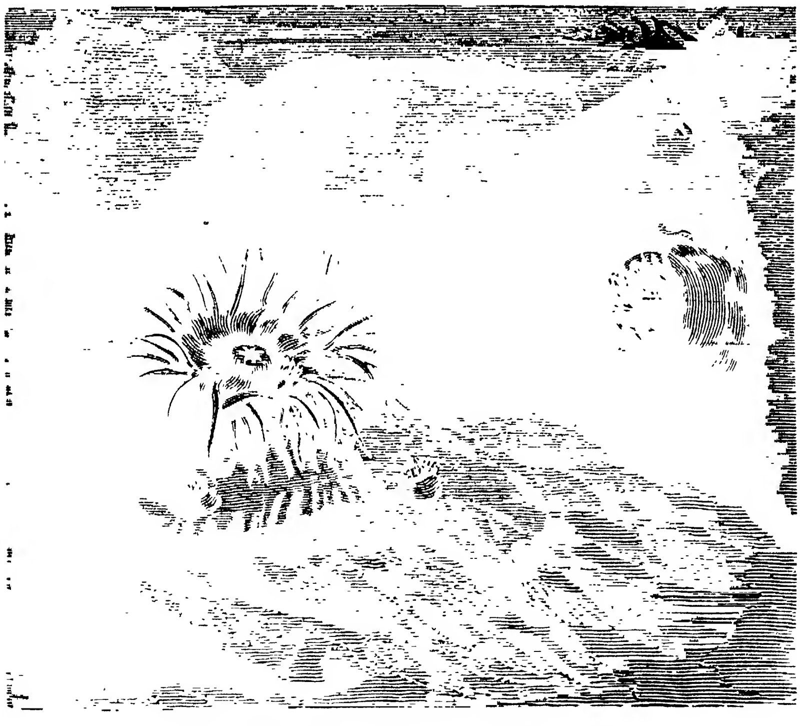

Fig. 4.—Birth of the Sea-Anemone (*Actinia equina*).

Every living being arising either directly or indirectly from an egg, we find the anemones to agree with the higher animals in that each represents the full development of a single egg or "ovum." These animals, like the Hydra, may be artificially divided, so as to produce two new anemones by the division of one; and their neighbours, the Corals, increase naturally by *fission* or division of body, as well as by *gemmation*, or budding. Hence the power of the Corals to form complex colonies, and to increase indefinitely in numbers. But the common sea-anemones remain each single and separate, as do higher animals, and show no tendency as a rule to imitate the colonial organisms (such as the Zoophytes and Corals), of which they are near neighbours. Certain of the near relations of the anemones, however (*e.g.*, *Zoanthus*), may exhibit a colonial structure; these anemones existing in small family groups, the members of which are connected by a kind of creeping root.

The eggs of the anemone pass through well-defined stages of development, and the young may be discharged in large numbers from the mouth of the parent, having undergone development within the "intermesenteric chambers" (Fig. 3, *d*). Each anemone egg presents exactly the same structure as every other egg. It is a mass of protoplasm, with a central speck, *the germinal vesicle*, and this latter exhibits another and smaller speck, known as the *germinal spot*. The egg (Fig. 5, A) undergoes division (or, as physiologists term it, *segmentation*—B, C, D) of its substance; and in the *morula* stage, when the egg has become fully divided into numerous cells, it may leave the parent body, and swim freely in the sea by means of the cilia with which it is provided. These cells then arrange themselves into two layers enclosing a central cavity, this stage being known as that of the *planula*. Then a mouth appears at one end of this oval "planula," thus forming what is known as the *gastrula* stage. The interior of the body becomes the future stomach-sac, whilst below and at the sides of this sac the body-cavity itself is formed, and sac and cavity thus come to be in the full communication we see in the perfect anemone. Then the mesenteries appear to be developed in the manner already described, and the stomach-sac becomes thus connected to the body-walls, whilst with the growth of tentacles and the fixation of the body, the young anemone assumes (E, F), in all points, save in size, the form of the adult.

Such are the ordinary changes through which the germ, or ovum, becomes the full-grown anemone. In its development, that egg evinces stages which are common to the eggs of all animals, and the higher animals, it is noteworthy, pass in the course of their development through a "gastrula stage," at which, with little further modification, the sea-anemone may be said to rest.

The anemone does not stand alone in the world of animal life. It is not separated by peculiarities of structure from other animals, but, on the contrary, serves in the hands of the zoologist as the type of a very large group of the animal kingdom.

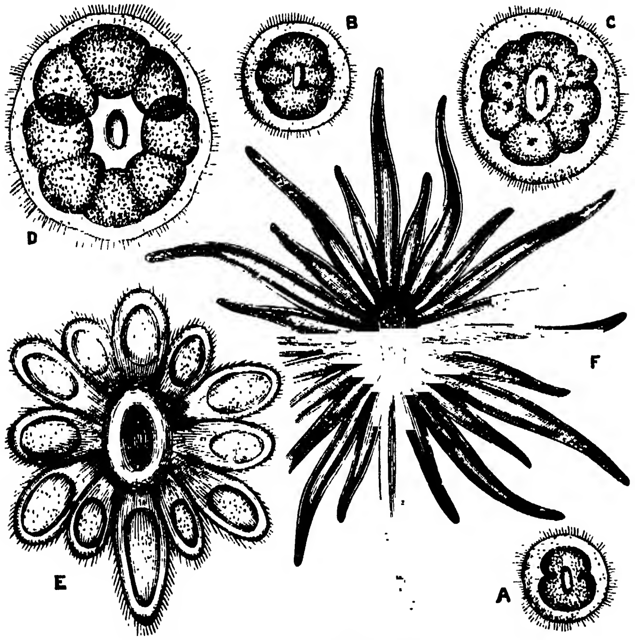

Fig. 5.—Development of Sea-Anemones.

Let us try to see what anemone structure teaches us respecting the type, or general build, of other animals. The anemone's character may be summed up by saying (1) that its body substance consists of two chief layers (ectoderm and endoderm); (2) that its mouth opens into a stomach-sac, which in turn freely communicates with the general cavity of its body; (3) that it possesses thread cells; and (4) that the parts of its body are arranged in *radial* fashion round a central point of the mouth. Now, if we examine such animals as Corals, "dead men's fingers" (Alcyonium), and the like, we find these characters of the anemone to be exactly repeated in their structure. We may, in a word, use the anemone as the type and representative of all Corals, and a host of other and allied animals. And if we omit the stomach-sac, we may find that the facts of anemone structure will make it the type of the hydras, sea-firs, jelly-fishes, and zoophyte groups likewise.

Thus we discover that in gaining an idea of sea-anemone structure, we have been laying a solid foundation of knowledge respecting that large body, or type, of animals known as the *Cœlenterata.* This type includes the anemones, corals, zoophytes, jelly - fishes, and allied animals, which agree in the main details of their conformation with the animal we have just examined. Their bodies exhibit the same two-layered arrangement, the same development of thread cells and muscles, and an essentially similar, or allied, disposition of stomach-sac to that noted in the anemone. Natural history study thus becomes a comparatively easy study, when we discover that every animal agrees with a number of other animals in the general plan or type of its body. Not the least important parts of zoological teaching are founded upon facts culled from some of the most familiar animals by which we are surrounded; this is the end aimed at in these pages, and no organisms are better fitted for this purpose than the "living flowers" which grace every rock-pool, and brighten the rocky sea-shore with their resplendent hues.

HOW BUILDINGS ARE PROTECTED AGAINST LIGHTNING.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.

In the year 1764 the steeple of St. Bride's Church, in Fleet Street, London, was struck by a flash of lightning, and seriously damaged. This accident occurred just at the time when the attention of scientific men had been strongly drawn to the electrical nature of thunderstorms, by the memorable experiments of Benjamin Franklin. Dr. Watson, who shortly afterwards became a Vice-President of the Royal Society of London, and who had been on various occasions the means of communicating the proceedings and views of Franklin to its Fellows, in consequence was induced to make a careful inquiry into the mechanical effects of the discharge, and he found that the lightning had passed to the earth along a track which was partly composed of iron, and partly of mason-work and timber, and that wherever the discharge had traversed thick rods of iron, it had left no perceptible traces of its passage, but that where it had passed through masonry or wood, it had shattered the material into fragments. The lightning first struck the weather-cock which stood on the top pinnacle of the steeple, and then ran down the stout iron bars by which this was held aloft in its place; effecting so far no injury; but when it reached the lower extremities of these bars it destroyed several large stones as it leaped across to other masses of iron, which had been built into the masonry to give strength to the wall; and further down, where no more iron was to be found, it made such vast gaps in the structure that not less than ninety feet of the steeple had to be taken down and rebuilt. The fact which was accidentally illustrated in this occurrence is one which is now well-known to electricians. When concentrated and powerful electrical discharges occur through material substances that are capable of affording them a ready and easy passage, no permanent disturbance is caused in the adhesive coherence of the molecules. But when they make their way through substances that afford considerable resistance, the molecules are thrown into paroxysms of convulsion, and very frequently are so widely separated from each other that the structure is destroyed.

As a general rule the greater the resistance that is offered to the passage of an electrical discharge the more marked are the disrupture and destructive effects that are produced when the transmission takes place; or, as the same fact is expressed in the more technical language of the electrician, the worst conductors are most liable to be injured by the passage of discharges of high tension. This simply means that there is an inert resistance exerted by the molecules of non-conducting substance, which prevents the vibratory movements amongst themselves—of which electrical transmission consists—from being established until the disturbing force is roused into an energy that suffices to tear them asunder at the same moment that their cohesive stubbornness is vanquished. When the electrical transmission is made through easily conducting substance, the molecular vibration is established without the occurrence of any very strong molecular resistance, and consequently without any strain that is dangerous to cohesive integrity. The propagation of the vibratory state is set up before the disturbing force is intensified by persistent resistance into destructive strength.

But when powerful electrical discharges are passed through substances of good conducting capacity, the molecular disturbances that are propagated through the mass are manifested to observation in another way. If a discharge of such character, for instance, is transmitted through a metallic wire of moderate dimensions, the wire becomes hot to the touch at the instant of the passage. In that case the heat is, in reality, due to the vibratory movement of the molecules of the wire. The disturbance takes effect in heating the wire, instead of in tearing asunder its molecules. But the amount of heat that in such an instance is produced depends upon two circumstances. It is affected both by the dimension of the wire, and by the intensity, or energy, of the discharge. The larger the amount of the discharge through any particular stretch of wire, the greater is the heat; or, again, the smaller the wire through which any particular discharge is passed the more its temperature is raised. A frequently-exhibited experiment of the lecture-room consists in turning a fine platinum wire red-hot by the transmission of a sustained current of electricity through it. The wire is easily caused to glow so brightly that its luminosity becomes evident in full daylight. If, in this experiment, the wire is either made smaller, or shorter, the incandescence becomes more intense, and the luminosity more brilliant. The wire may, indeed, be ultimately made either so fine or so short, that it is melted by the heat. A long strand of very fine copper wire laid along upon white paper remains only as a dark stain of metallic dust impressed upon the paper, when the discharge of a powerful battery of Leyden jars is passed through it. Metals of inferior conducting capacity in a similar way are more heated than metals of a better conducting power, and of equal dimensions. Thus platinum wire is more heated than iron, iron more than silver, and silver more than copper. If a wire is made of alternate links of platinum and silver, each link being of precisely the same thickness and length, when a sustained electrical current of sufficient intensity is passed through it, all the platinum links are raised to a shining red heat, whilst the intervening links of silver remain still dark. As a general rule, metals are of good conducting capacity, and afford a ready transmission for electrical disturbance. But they vary very much indeed amongst themselves in their capacities in this particular. Thus, copper stands foremost amongst them for its conducting power; silver has about one-third the conducting capacity of copper; brass a little less than that; iron less than brass; tin and lead considerably less than iron; and platinum is very nearly equal in transmitting capacity to iron.* This capacity of metallic bodies for the easy and unresisted transmission of electricity without material derangement of their molecular state, is the circumstance which has been taken advantage of by science in establishing an organised defence against the injurious effects of lightning.

In the autumn of the year 1750 a letter was written from Philadelphia by Benjamin Franklin to a friend in London, in which he dwelt upon his conviction of the absolute identity of lightning and electricity, and urged that all damage from lightning might be certainly prevented if iron rods with sharp points were fixed to the highest parts of buildings. This was the first clear and definite conception of the idea of the lightning-rod which is now so extensively employed. The suggestion was at once thrown into the form of a pamphlet and printed in London. It was eighteen months after this time, namely, in May, 1752, that electrical sparks were for the first time drawn from the clouds at Marly-la-Ville, near Paris, through an iron rod one inch in diameter and eighty feet high, which was held up towards the clouds by a wooden scaffold, and which had been erected by M. Dalibard in pursuance of the plan suggested by Franklin. The sparks were in the first instance obtained by an old soldier, who had been left in charge of the apparatus, during the passage of a thunderstorm overhead. It was on the 4th of July in the same year, 1752, and therefore nearly two months afterwards, that Franklin's own celebrated experiment with the kite was performed, and that sparks were drawn from the thunder cloud in a similar way through its wet string. In the same year Franklin carried his own idea into practical effect, by erecting an iron rod upon his house in Philadelphia. This rod was furnished with a steel point projecting eight feet above the roof of the house, and it was carried five feet into the ground. It was essentially the first lightning-rod constructed for purposes of protection. The first conductor erected in England was set up in 1762, by Dr. Watson—already alluded to as the enthusiastic advocate of Franklin's views—over his residence at Payne's Hill, near London; this rod had been erected upon Dr. Watson's house just two years at the time of the destruction of the steeple of St. Bride's Church.

Under the earnest support of a few scientific men, the practice of erecting lightning-rods for purposes of protection from this time gradually forced its way into public notice. In the year 1769 the Dean and Chapter of St. Paul's applied to the Royal Society of London to tell them how they should set about fixing a rod to their noble cathedral. The first rod set up on the continent of Europe was attached to the church of St. Jacob, at Hamburg. This was erected in 1769. In 1771, the celebrated naturalist, Professor de Saussure, fixed a conductor upon his house in Geneva. The practice was, nevertheless, still looked upon with much doubt and suspicion. As recently as 1838 the Governor-General and Council of the East India Company ordered that all lightning-rods should be removed from arsenals and powder-magazines in India, on account of the danger which their employment involved.

The French were from the first keenly alive to the importance of adopting Franklin's recommendations in the matter of protection against lightning. Some opposition had in the first instance to be encountered, chiefly on account of the jealousy and misapprehension of the Abbé Nollet, who deemed himself the great scientific authority of the day in such matters, and therefore was inclined to resent the intrusion of a new prophet into his domains. He at first denied that there was any such person as the alleged author of the new system in existence, and then when the London pamphlet had been translated into French, he shifted his ground and maintained that the proposed innovation was both dangerous and inefficacious. A most admirable French designation was nevertheless contrived for Franklin's rod. It was aptly called the "Paratonnerre," a French compound word which signified the fender off* of lightning, and in 1823 formal instructions were drawn up by the Academy of Sciences at Paris, and adopted by the French Government, for the scientific construction of the apparatus. An amended and improved form of these instructions was again issued in 1854. The memorandum of 1823 was signed by the august name of Gay-Lussac, and that of 1854 bore the scarcely less distinguished signature of Professor Pouillet. Additional memoranda were supplied by the Academy in 1855 and 1867. No proceedings of a similarly intelligent and practical kind have hitherto been attempted in England, and these French documents have accordingly remained the authoritative guide of our own architects and engineers in their practice. The history of Franklin's invention constitutes one of the most charming and interesting episodes in the annals of physical science. But the subject is unfortunately too long to be more fully dwelt upon where all the space at command is required for a more immediately practical object.†

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* This estimate is the one derived from Prof. Ohm's experiments. Other experimenters give different results.

The first thing to be considered in arranging for the protection of any building against lightning is the metallic conductor, which is to be provided to serve as the main channel for the electrical discharge. The self-same plan which was adopted in the first instance by Franklin has still, in the main, to be pursued. A continuous metal bar, or rod, is to be attached to the building so that it projects into the air above its highest part, and dips into the earth below its foundations. This rod must, above all things, be of sufficient capacity for the work which it is intended to perform; that is to say, it must be so thick that it would not offer any material resistance to the largest discharge of lightning that could in any circumstances be thrown upon it from the clouds. It must be of such ample dimensions that it would not even be heated to any large extent by such a discharge, for heat in such circumstances, it must be remembered, would imply the presence of resistance, or obstruction, and the object of the contrivance is that the transmission shall be unimpeded and free. Franklin used iron for his rod on account of its comparative cheapness. But copper is now very much more generally employed, for various reasons. It is more readily bent so as to be applied closely to all the irregularities of the building. It is less easily corroded by moist air; and it has a very much higher conducting capacity. Iron may be as effectively employed as copper; but if this is done the main stem of the rod must be six times as large as it would need to be if it were of copper; that is to say, it must have six times the amount of metal in any given length, such as a foot, or a yard; it must have six times as large an area when it is cut across. And beyond this it must also be examined after its erection, from time to time, to make sure that its conducting capacity has not been diminished by the influence of corrosion.

The exact size which a copper bar or rod needs to have to insure this essential condition of an unimpeded passage for the largest discharge of lightning that could fall upon it from the clouds is not certainly known. It is not practicable, either, to refer this uncertainty to the questioning of direct experiment, where it is lightning that has to be drawn upon for the prosecution of the test. All that can be done, is to employ a bar that is larger than any that has been known to be injured by a discharge. So far as practical experience has been yet gained a strip, or bar, of copper one inch wide, and an eighth of an inch thick appears to be of ample dimensions, for all practical purposes, where the conductor does not exceed eighty feet in length. Such a strip, or a rod of equal sectional area, would weigh a little less than half a pound to the foot. It must not, however, be overlooked that since the resistance of a conductor increases with its length, as well as in proportion to its smallness, still larger rods must be used, wherever the greater extent of high and large structures has to be dealt with. For each extent of eighty feet another such strip would need to be added the whole length. The strip, or bar, may be safely and advantageously attached directly to the masonry, or brickwork, of walls. No better plan can be pursued than to clasp a bent strip of copper round the conductor, and fix this to the wall by copper nails driven into the joints as shown in Fig. 1.

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* From *parer*, to "ward off," and *tonnerre*, lightning. An excellent and most significant designation, for which there is unfortunately no equivalent term in the English language.

† A very good sketch of this passage of the history of electrical science is to be found in a treatise on lightning-conductors published by Richard Anderson.

The exact form of the conductor, however, is not a matter of any real consequence, provided only that there be thickness enough of the metal. The strip is sometimes rolled up into the form of a hollow cylinder, or pipe. It is sometimes moulded into the shape of a solid cylindrical rod, and it is very commonly replaced by a rope of copper wires, twisted together. Fig. 2 represents the kind of copper wire rope which is most frequently employed, attached to the wall in a similar way to the flat conductor.

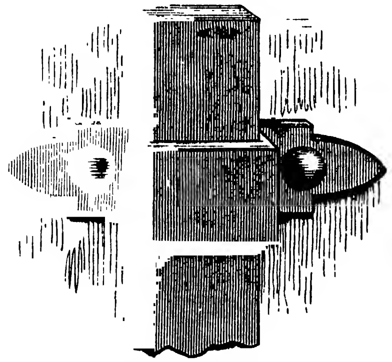
Fig. 1.—The Method of fastening a flat Lightning-rod to a Wall, by a Copper Strap and Nails.

This rope consists of seven strands, with seven wires in each, or forty-nine wires in all; and weighs about two-thirds of a pound to the foot, when used for the defence of a building of moderate size. Larger ropes are provided for larger structures. The conductor, whatever its length, must be absolutely continuous from end to end. If under any circumstances separate pieces have to be joined up in the length, these must overlap by clean metal surfaces, some inches in extent, and be closely riveted, or bound together in such a way as that the intrusion of moisture between the surfaces in contact shall be prevented. Wherever it can be done, the joints should be very carefully covered over by a coating of solder, to prevent the corroding influence of moist air. But joints, as a general rule, are not required in the main stem of the conductor, because both ropes and strips, or, as these are technically termed, *tapes* of copper are now manufactured of any length that is required. A rolled copper tape which is very flexible, and therefore very convenient both for transport and for application to irregular surfaces, is now being gradually introduced by electrical engineers, and is entirely deserving of general confidence.

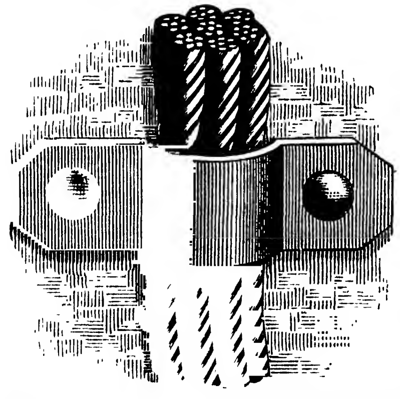
Fig. 2.—The Rope of Copper Wire which is frequently employed in the construction of Lightning Conductors.

When a copper conductor of this kind has been properly applied to the walls of a building, its efficacy as a protection in a large measure depends upon the fact that when a lightning-charged cloud hovers in the air a little distance above the top of the rod, it becomes powerfully electrical, through the influence of induction, with a charge of an opposite kind to that in the cloud. And there is therefore a strong tendency for the charge in the cloud to pass into the rod, and for the charge in the rod to issue to the cloud. If in such circumstances the tension becomes so strong that the charges can leap across the intervening gap of air, a flash of lightning occurs. But as, in obedience to the direction of the tension, it goes at once into the rod, it there finds an easy path prepared for its transmission to the earth, and traverses this path without producing any mechanical disintegration between the molecules of the conductor. Such is, essentially, the service which the conductor renders when an actual stroke of lightning takes place. It affords an easy and open channel which the lightning is quite sure to take in preference to the harder task of making its way through the impeding and resisting structures of the building.

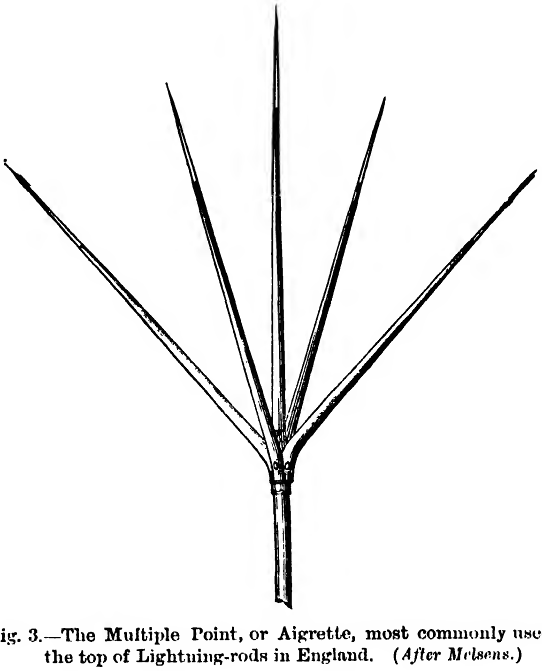
Fig. 3.—The Multiple Point, or Aigrette, most commonly used at the top of Lightning-rods in England. (*After Melsens.*)

But there is another way in which the lightning conductor also contributes to protection. It lessens the tension, and so diminishes the striking power, of an approaching storm-cloud. This, however, will be best explained by a reference to the method in which the conductor is finished above where it projects towards the cloud.

In every case a lightning conductor is so planned that it terminates above either in a point or in a cluster of points arranged in some such way as is represented in the accompanying woodcuts (Figs. 3 and 4). Fig. 3 shows the form in most general use in England. Fig. 4 represents the very excellent modification that has been introduced by M. Callaud in France, in which sharp radiant spikes are fixed upon the upper surface of a flat ring of copper, with one long terminal point rising in the centre above. The main stem in each case is a copper rod about three-quarters of an inch in diameter, and so contrived that it can be firmly screwed into the upper end of the conductor. The tips of the points are sometimes very advantageously made of an alloy formed by mixing together 835 parts of silver, and 165 parts of copper, because this compound does not readily suffer corrosion from exposure to the air. Sharp tips of this alloy are prepared about two inches long, so that they can be screwed into the branches of the copper rod. The cluster itself is fixed so that the tuft of points projects about five feet above the highest part of the building to which it is attached. The pointed form is given to the top of the rod on account of the power which conductors of this shape possess of facilitating both the discharge and the inflow of an electrical stream. They dispose the escape to take place in the condition of a gentle continuous current, instead of in the more impulsive and less controllable form of an abrupt and instantaneous spark. That such is really the action of the point is experimentally shown when a sharp sewing needle is brought near to strips of paper which have been made divergent by an electrical charge. The strips lose their divergent power, and fall suddenly together, whilst the needle is still two or three feet away.

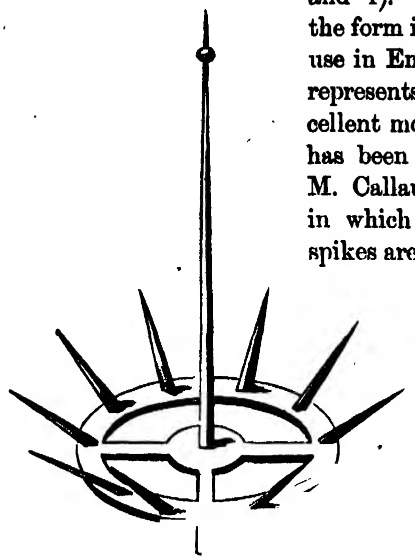

Fig. 4.- The Multiple Point recommended in France by M. Callaud. (*After Melsens.*)

The consequence of this peculiar influence of the point in the case of a lightning conductor, is that when a charged thunder-cloud hangs in the air over the conductor, the charge which has been inductively heaped up in it at the outer end begins immediately to stream gently away into the cloud, at the same time that the accumulated charge of the cloud is drawn in a like silent way through the point, and transmitted to the earth. The cloud is thus effectively exhausted of its charge without having developed disruptive energy enough to cause an actual outburst of lightning.

But the lower extremity of a lightning-conductor, where it passes into the earth, is even more important to the efficient action of the apparatus than the pointed summit which is projected into the air. As in the case of the rain pipe which is prepared to protect a house from injury by wet, it would be of small consequence that the pipe itself were of ample dimensions for the passage of the rain, if it were narrowed and obstructed at its outlet at the bottom; so is it also with the conductor which is provided for the safe transmission of the lightning. If there be not room enough for the pent-up downpour, whether it be water or electricity, to escape, there must be a mischievous overflow above; and the overflow, if it be of electric fire, may obviously be attended with more disastrous results than if it be merely a deluge of water. Although the water and the electrical force are in truth quite different things, this comparison is by no means overstrained, for the earth is the great reservoir of both. Whatever amount of either is raised temporarily into the air, must sooner or later flow back again to the ground, and if conduits are provided for the conveyance of the flow, they must be so planned as to permit an unobstructed outflow.

The outlet for the discharge of lightning from a conductor into the earth is, however, a matter of extended superficial space, rather than of internal cavity, such as water would require. The transmission of the electrical discharge, on account of the expansive repulsion of the force, is accomplished, mainly along the outside, or superficial, molecules of the conductor, rather than within. What is therefore required in providing the outlet into the earth is an amplified expansion of the mass. The conductor must be enlarged where it comes into communication with the ground. It is not enough, as is too commonly conceived, that the rod shall be thrust a few inches into the earth. It must be carried a considerable distance into the soil, and must be placed everywhere in the most intimate connection with it. This must on no account be lost sight of. A lightning-rod with an insufficient earth contact is not only useless, but dangerous in an extreme degree, and the more ample its own dimensions, the more imminent the danger, if there be an obstructed outlet beneath; the more likely to lead incidentally to that overflow of the devastating electric fire, which it is its intended function to prevent. It is not possible to insist too vehemently upon this, because mistake, or oversight, in this particular is a more frequent source of injury by lightning than any other circumstance that is encountered. In nearly every case where damage has occurred to buildings that have had lightning-conductors attached to them, it has been found that the mischief can be traced to this cause—an overflow brought about by impeded outlet to the earth. When a lightning-rod of ample capacity, and of sufficient earth-outlet, receives a stroke of lightning, the discharge passes down it in the form of a gentle stream which has not the slightest inclination to burst out anywhere. A living person might stand close to the rod at the time of the discharge without incurring any risk. But if the same stroke were falling upon a rod with insufficient outlet to the earth, being thereby impeded in its flow it would pass haltingly along, and with a constant inclination to burst out laterally by the way, so that any one standing in close neighbourhood to the rod at the time of the discharge would be in imminent danger of receiving some portion of it through himself. As an absolute matter of fact, when a stroke of lightning passes to the earth through a building furnished with a conductor, it does not quite confine itself to the open path. It avails itself of all the substances that lie in the direction of its track. But it distributes itself amongst them in proportion to the facility with which it can make its way. Very much the largest part goes by the easiest route. With a large conductor of ample earth-contact very nearly the whole of the discharge passes harmlessly through its easy line, so that only a very minute, and quite unimportant, portion is left to traverse the more difficult and undisturbed route.

It is a very interesting incident in the history of the lightning-rod that Franklin was quite aware of the importance of a large earth-contact, notwithstanding the gross blunders that have been continually made in regard to it since his time. In the year 1772, when he chanced to be residing in England, he acted as a member of a committee constituted to consider the best form of lightning-rod for powder magazines, and he himself drew up a report in which there occurs the following most notable passage:—"In common cases it has been judged sufficient if the lower parts of the conductor were sunk three or four feet into the ground, till it came to moist earth; but this being of great consequence we are of opinion that greater precaution should be taken, therefore we would advise that at each end of each magazine a well should be dug so as to have in it at least four feet of standing water. From the bottom of this water should rise a piece of leaden pipe to, or near to, the surface of the ground where it should be joined to the end of an upright bar," to be itself connected with the earth end of the conductor. Yet in the face of this sound doctrine, even at the present day men of some scientific attainment may be sometimes heard to say that it is enough for a lightning-rod to have its base just thrust a few inches into the earth. The notion in such instances is that it cannot be a matter of any further moment where the electric discharge goes to, if it is once got as low as the earth. The fallacy of this argument is that it entirely overlooks the most important condition which has here been so urgently insisted on, namely, that an electrical discharge moves haltingly, and with a strong disposition to attempt a lateral outburst, through a rod which has an obstructed outflow, whilst it is devoid of all such mischievous tendency when it passes through a rod with a capacious earth contact.

In the amended instructions of the Academy of Sciences in Paris, issued in 1855, it was urged that a lightning-rod should invariably have a connection with water beneath the ground, or with moist earth, and to make sure that this essential condition was satisfactorily secured, it was advised that the rod, after reaching the earth, should be divided into two subordinate branches, and that of these, the one should be carried deep into the ground until it reached some permanent reservoir of water, whilst the other was trailed superficially along only a few inches within the ground, so that it might be in a region that was most readily moistened by rain. The earth-contacts of the Palace of the Louvre were forthwith remodelled upon this plan. This was a very important step in the right direction. Dry earth is in no case a really good conductor; very many of the accidents which have occurred in connection with the presence of lightning-rods have been due to some oversight in this particular. Father Secchi of Rome had occasion, in 1872, to draw up a report in which he dwelt emphatically upon the need of a very large surface of conducting material for the discharge of lightning into the ground. In this document, in reference to this particular necessity he very strongly marks the conclusion at which he had himself arrived, for he roundly and most truly says, "there never can be too much" facility for the discharge.

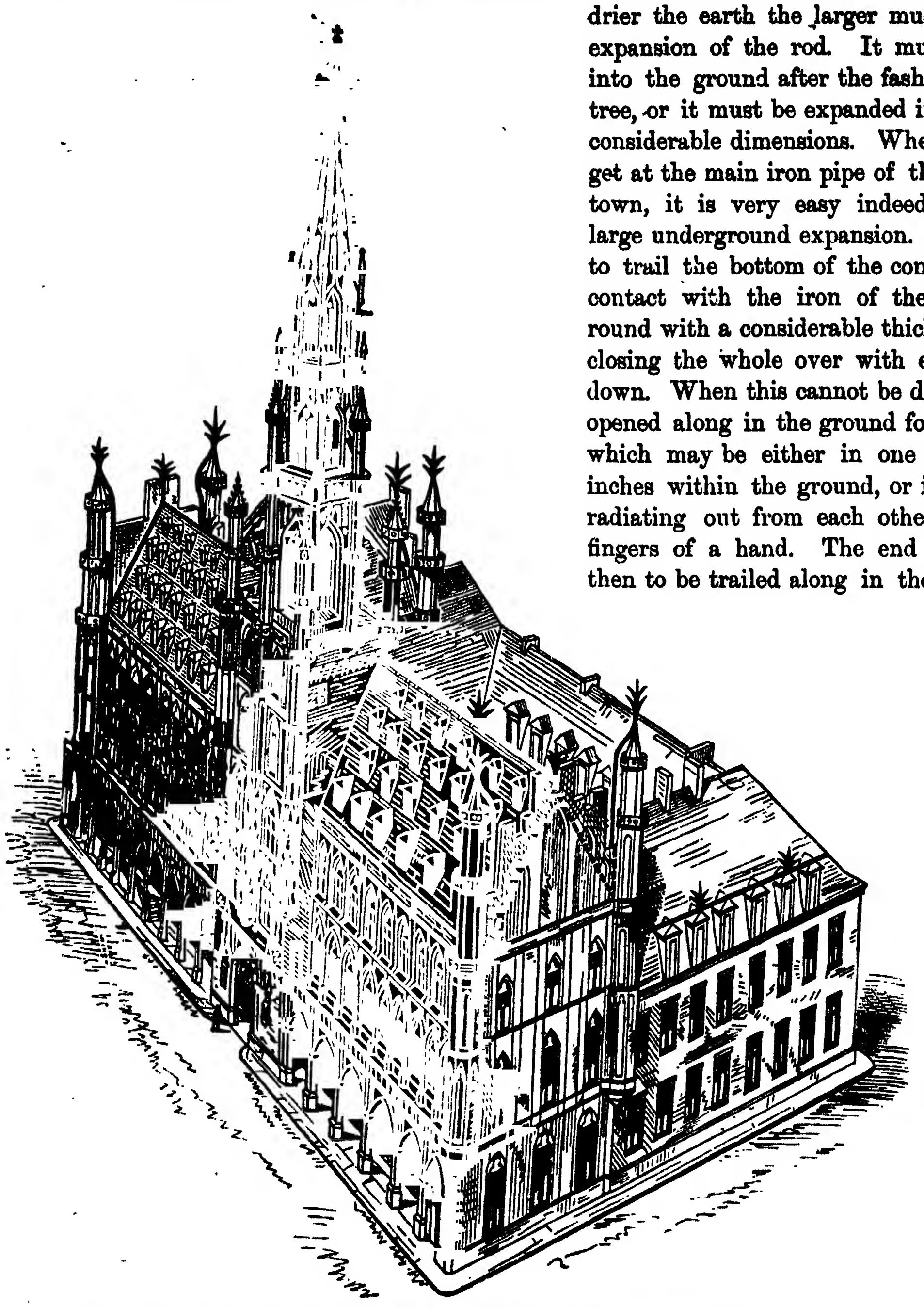

Fig. 5.—Showing the System which has been adopted for protecting the Hôtel de Ville at Brussels from Lightning. (*After Melsens.*)

It is quite possible for a skilful electrician to make a good earth termination for a lightning-rod in even dry soil. But he can only do so by rendering the superficial contact between the conductor and the ground very large indeed. The great principle to be observed in such a case, is that the drier the earth the larger must be the downward expansion of the rod. It must either branch out into the ground after the fashion of the roots of a tree, or it must be expanded into a bulbous root of considerable dimensions. Whenever it is possible to get at the main iron pipe of the water supply of a town, it is very easy indeed to accomplish this large underground expansion. It is only necessary to trail the bottom of the conductor along in close contact with the iron of the main, and pack it round with a considerable thickness of broken coke, closing the whole over with earth, and beating it down. When this cannot be done, a trench must be opened along in the ground for at least thirty feet, which may be either in one straight line a few inches within the ground, or in branched divisions radiating out from each other like the expanded fingers of a hand. The end of the conductor is then to be trailed along in the trench, dividing it into corresponding branches, if the branching plan is preferred, and then packed round with broken coke, the whole being finally covered over by earth, and beaten firmly down. Not less than three bushels of coke must be employed for completing the earth-contact for a building of ordinary size, and very much more where a larger structure is concerned. The reason for the use of the coke is, that being itself a tolerable conductor, it enlarges the conducting contact with the ground to the size of its own mass, and that it does this at a comparatively trifling cost—being in itself so very much cheaper than the same quantity of pure metal, such as copper. It also has the further recommendation that it is not corroded by being buried in moist earth as most metallic bodies are. It virtually confers the large bulbous root upon the conductor, where it is buried up in the ground at a very small outlay.

A good lightning-rod thus takes somewhat the form of a tree. It has a compact central stem, it has branches spread out like point-tipped leaves into the air, and it has expanded rootlets under the ground. The branches above are distributed to the ridges, and to all the prominent parts of the building, which is under their protection, and wherever there are any large metallic masses employed in the structure, such as sheets of lead, iron pipes, or metal balconies, each one of these must be connected with the main system of the conductor by its own metallic strip, and must also have its own projecting air point. The air-terminals thus assume the state of a widely-spread bundle of points opening out to the sky, and projecting everywhere beyond the building. If the structure be small, three or four such terminals distributed to the loftiest chimneys, and to the most prominent ridges and gables, may be as much as is required. But if the building is large, the points must be proportionally multiplied and the bundle-like distribution be increased. In the Hôtel de Ville at Brussels—which is perhaps one of the best examples of lightning defence applied to a public building upon a large scale—no less than 426 points have been provided. The main branches of the conductor are carried along all the ridges of the roof, and shoot up as a complete forest of tufted spikes from all the pinnacles and towers (Fig. 5). The chief front of the building has a pinnacled turret and spire rising 297 feet above the ground, and bearing at the top a gilt statue of St. Michel, flourishing his sword over the prostrate dragon (Fig. 6). The point of this sword serves as a very appropriate termination to the system of conductors. But it is not relied upon alone. In order to make assurance doubly sure, the platform upon which this figure stands is surrounded by a vast chevaux-de-frise of forty-eight spikes radiating out to all quarters of the sky in a circle sixteen feet in diameter. The statue is pivoted upon a stout central bar of iron, which rises out of a lead-and-copper-covered cupola, and this metallic mass is closely connected with the highest range of the coronet of spikes.

Eight iron rods run down from this lofty spire, and are joined below by numerous other rods that descend from the subordinate pinnacles and spires, and these rods (shown at *c*, in Fig. 7) are all at last collected into one metallic mass in the inner court, about three feet from the ground, as shown at *d*, in Fig. 7, by being plunged into a square iron box quite filled with zinc, that has been poured in round the rods in a molten state. Three times as many rods distributed into three distinct bundles then issue from the iron box beneath, as represented between *d* and *e*, in Fig. 7, to establish the connection with the earth, and of these one bundle passes down to an iron tank sunk into a water-filled well dug out beneath the foundations of the building. The second bundle is carried to the iron main of the water supply of the town; and the third is continued on in a similar way to one of the large iron mains of the gas supply. In this ingenious way not less than 300,000 square yards of earth contact have been secured for the lower termination of the system. It will not be deemed unworthy of a passing note that Professor Melsens, the skilful and bold originator and director of this admirable work, holds that even a large town

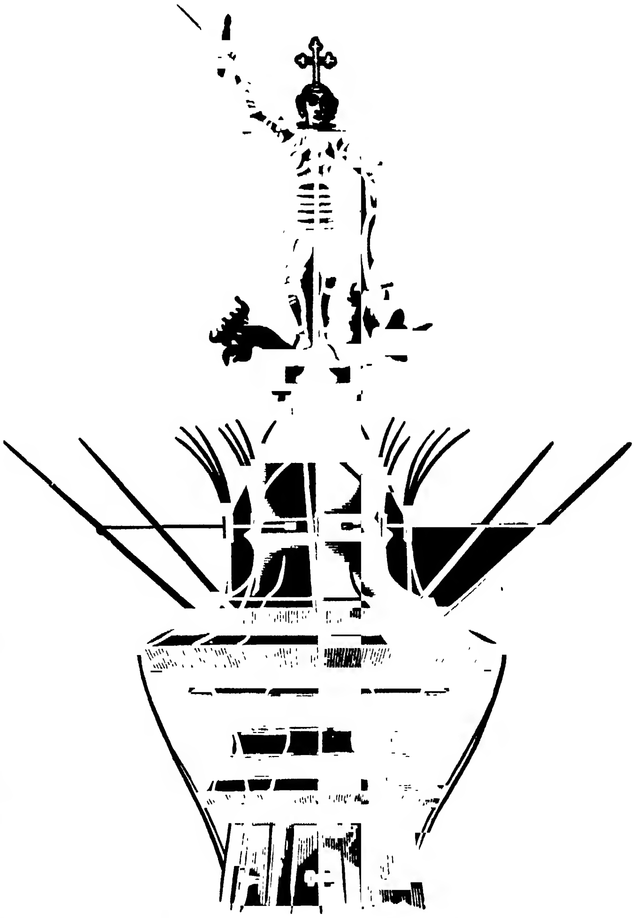

Fig. 6.—The Statue of St. Michel which surmounts the spire of the Hôtel de Ville at Brussels, with its subjacent coronet of tufted points. (*After Melsens.*)

should be defended from lightning in a similar way, by one general system of connected rods distributed to all the most prominent buildings, and issuing from one common earth termination of very ample capacity. Such a system is, no doubt, in principle, correct, although it may be difficult to carry it out in detail, and is therefore worthy of being followed in smaller works so far as each individual case permits.

The great principle, therefore, which has to be kept constantly and prominently in view in the construction of lightning-rods, is simply that the conductor shall be made as capacious as possible, and that there are three quite distinct ways in which ample capacity may be insured: (1) By the employment of large rods for the main stem of the conductor; (2) by the multiplication of the points which bristle up into the air from the highest parts of the building, and (3) by the amplification of the earth-contact under the ground. It should, however, also be known that it is practicable to ascertain how far in any individual case sufficiency of capacity has been attained, by testing the resistance which the system of conductors affords to a weak current of artificial electricity passed through it to the earth from a battery provided by the electrician for the purpose, although this requires a considerable amount of technical knowledge and skill in the operator to carry it into effect. Such tests need also to be repeated from time to time to make sure that the channel of outlet into the earth is not becoming accidentally diminished, or obstructed, through the influence of destructive corrosion.

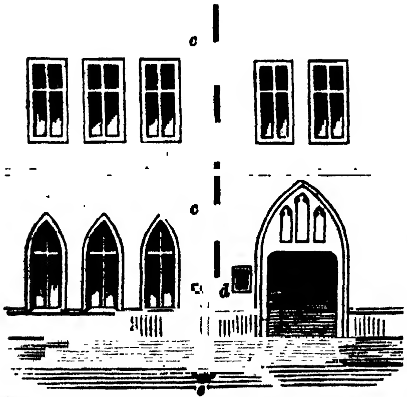

Fig. 7.—A Portion of the Inner Court-yard of the Hôtel de Ville, showing how the earth contact of the Lightning-conductor is managed. (*After Melsens.*)

In the memorandum of instructions which was issued by the French Academy of Sciences in 1823, it was laid down as a kind of law that every point of a lightning-conductor efficiently protects a conical space, which extends as far again round the centre of the base of the cone, as the cone itself is high. It is now known that this proportion is not implicitly to be trusted to. The presence of large masses of metal in a building, and some other circumstances with which practical electricians are familiar, may require additional precautions beyond those which are involved in its adoption. It may nevertheless be looked upon as a good general guide, subject to such incidental modifications. The lightning-conductor should be arranged so that no portion of the building presumed to be under its protection projects anywhere beyond the surface of such a cone, having a base four times as wide as the conductor itself is high, without an additional point being furnished to it, and placed in connection with the conductor. If the sketch in Fig. 8 be taken to represent a church with a lightning-conductor *a b* upon its tower, whose terminal aigrette, *a*, is 100 feet above the ground, and the lines *a e*, *a f*, be conceived to mark out a cone whose base is 400 feet in diameter, then the gable *c* would be beyond the area of protection, and it would be necessary that an additional point, or tuft of points, should be erected there, and connected with the main stem of the conductor as indicated at *d*. Any number of branches and points may be arranged upon the same general system where large buildings are concerned, as indeed is the case in the instance furnished by the Hôtel de Ville at Brussels.

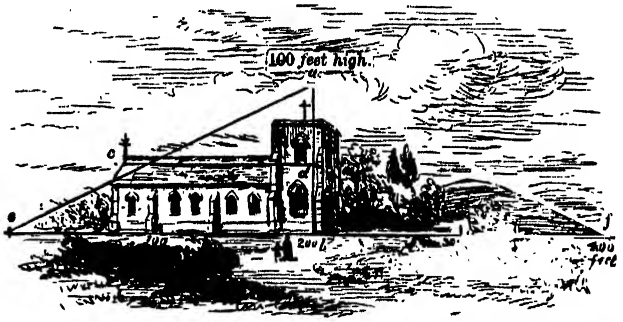

Fig. 8.—Illustrating the Conical Space considered approximately and rudely as protected by a Lightning-rod.

There is one measure of precaution which must never be lost sight of in arranging any system of lightning-conductors in towns. The rods must in no instance be carried anywhere near to small soft-metal gas-pipes, or there will be imminent risk of the discharge escaping deviously to the gas-pipes, on account of the very large and free metallic communication with the earth which these invariably possess, melting them during its passage, and setting fire to the gas which escapes at the damaged place. Very numerous instances are on record in which the discharge has burst in this way from a conductor with small earth contact through six feet of solid masonry to get to a gas standard, with large earth communication, fixed on the inside of the wall immediately opposite to the conductor. The obvious remedy for this danger, when for any reason a lightning-conductor is required to pass near to a small flexible gas-pipe, is that the conductor should be itself carried down to one of the *large mains* of the gas supply. By adopting this plan, it is clear that all risk would be effectually obviated, because a discharge of lightning would not, under such circumstances, need to strike across to the gas-pipe to get to the earth communication of the main, having already its own connection established with that same earth contact by a nearer and easier route.

COAL GAS.

By J. Falconer King, F.C.S.,

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IN the early part of last century the then Dean of Kildare, the Rev. John Clayton, noticed a ditch about two miles from Wigan, in Lancashire, wherein the water, as he tells us, would seemingly burn like brandy, and the flame whereof was so fierce that several strangers succeeded in boiling eggs over it.

Desiring to ascertain the cause of this phenomenon, Mr. Clayton hired a person to make a dam in the ditch, remove the water, and then dig down into the earth. When the excavation had proceeded about half a yard, a bed of shelly coal was reached; a lighted candle was then put down into the hole, when the "air" caught fire and continued to burn. In order to prove the truth of his supposition that the inflammable air and the coal were somehow connected with each other, he procured a sample of the latter, and subjected it to distillation in a retort heated by means of an open fire. At first there was produced only a "phlegm," but afterwards there appeared a black oil, and finally a "spirit arose." This spirit he could "in no way condense," but he found that as it issued out in a stream it very readily caught fire when brought in contact with a lighted candle, and continued to burn with violence.

Having a mind, as he says, to try if he could save any of this *spirit*, Mr. Clayton adjusted a *turbinated* receiver to his apparatus, and to the exit-pipe of the receiver he attached an empty bladder, which as the *spirit* arose was blown up and filled. The *spirit* as thus stored in the bladders he again tried in various ways to condense, but all his efforts in this direction were in vain.

"Then," to use his own words, "having a mind to divert strangers or friends, I have frequently taken out one of these bladders and pricked a hole therein with a pin, and compressing gently the bladder near the flame of a candle till it once took fire, it would then continue flaming till all the spirit was compressed out of the bladder; which was the more surprising because no one could discover any difference between these bladders and those which were filled with common air."

Thus was coal gas discovered; and it is curious and interesting to note that the process which Mr. Clayton employed to manufacture one or two bladders full of the gas with which to amuse his friends, is essentially the same as that which is employed in the present day for the production of the enormous quantities of this material, now used so extensively as a source of light and heat.

Nearly a century and a half have passed away since the discovery of coal gas was made, and yet not much more than sixty years have elapsed since it came into general use as an illuminating agent. Various reasons have been assigned for this long delay in the useful application of this most important discovery. As was to be expected, such a notable discovery as that of Mr. Clayton's led to many experiments being made, but these were mainly of a philosophical character. Neither Mr. Clayton nor any of his contemporaries seem to have thought of making use of the new gas for lighting purposes, and it was not until the year 1792 that it was first so employed. In that year, memorable in the annals of gas illumination, a Scotsman, named William Murdoch, then residing at Redruth in Cornwall, to whom is due the honour of first turning the result of Mr. Clayton's discovery to practical account, lighted his house and office with coal gas made in an apparatus of his own construction. Three or four years afterwards Murdoch removed to Ayrshire, in Scotland, and there he manufactured and utilised coal gas much in the same way as he had done in Cornwall. Thus—though, no doubt, on a very small scale—was the power of gas as an illuminating agent fully proved. Not, however, till the year 1798 was gas used commercially as a substitute for the old-fashioned oil lamps and candles, and even then it was employed to a very limited extent only.

In the year 1805 the cotton mills of Messrs. Phillips and Lee at Salford were lighted with gas; in 1809 an application was made to Parliament for an Act to incorporate a company, to be called "The London and Westminster Chartered Gas-light and Coke Company," and the following year the charter was granted. The newly-formed company, though it had now obtained a charter from Parliament, met with much opposition from the general public. The idea of lighting a town with gas was looked upon as purely visionary; and as illustration of the opinions held by even some of the foremost men of the time, it may be mentioned that Sir (at that time Mr.) Humphry Davy regarded the proposal as being so supremely ridiculous that he asked scornfully whether it was intended to take the dome of St. Paul's for a gas-holder.

The engineer to whom the question was addressed had evidently formed a better opinion of the future in store for gas illumination than that possessed by the great chemist, for he answered by confidently expressing the hope that he might live to see the day when gas-holders would not be much smaller. This hope, the utterance of which was, no doubt, regarded as empty boasting, was realised far beyond what was ever evidently expected! The dome of St. Paul's is 145 feet in diameter, and there is now at least one gas-holder exceeding 200 feet in diameter.

The new gas company, meanwhile, struggled on against all opposition, going so far even as to supply many shops and houses with gas for nothing, in order, if at all possible, to entice the public to look with favour on the new light. This state of matters continued for nearly two years, and then slowly, one by one, the many obstacles in the way were surmounted. These obstacles, however, were neither few nor trivial. In the first place there was the unaccountably great and apparently perfectly unfounded prejudice entertained against gas, not only by the general public, but also by many eminent scientific men. Then the insurance companies raised many objections, one at least of which was extremely frivolous. If a gas-burner was left open accidentally, they asked in horror, what would be the consequence? To meet this a special burner was invented, which, however, was never afterwards used.

Following the lead of the insurance companies, the Government next interfered. They were not sure but that some demon of destruction might be lurking undetected in the apparatus in connection with the much-suspected gas-flame. They accordingly deputed a number of gentlemen to proceed to the works of the unfortunate gas company, and make a careful inspection of their premises, the result of which inspection was that the deputation strongly advised the Government to insist that the company should only erect small gas-holders, and that these when erected should be enclosed in strong buildings.

The first part of this recommendation was made apparently in the belief that gas holders are liable to explode, many people then, as now, believing that if a light was introduced into one of these large vessels a most disastrous explosion would immediately result. The fact of the matter is, that if a light was put inside one of these gas-holders it would simply be quietly extinguished without even igniting the gas. Gas will not burn, much less explode, until it comes in contact with the air, and these gas-holders contain, not an explosive mixture of gas and air, but merely gas, pure and unmixed, and therefore perfectly incapable of exploding. In these early days, however, the properties of gas were not so well understood as they are now, and therefore we can excuse the first part of the recommendation made by the deputation. The second part, however, in which they advised that the gas-holders should be surrounded with substantial buildings, is totally inexcusable. If the gas-holders were not liable to explosion these buildings were not required; and if there was any likelihood of their exploding, the presence of the buildings, far from doing any good, would in the event of an explosion increase the disastrous effects tenfold. The company protested and explained, but all in vain; they were compelled to erect the expensive and useless buildings.

Nor were their troubles yet at an end. On the occasion of the rejoicings for the Peace, in June, 1814, it was proposed to have a grand public illumination by means of the new light. For this purpose a large wooden structure was, by order of the Government, erected in St. James's Park. This was provided with more than ten thousand gas-burners, which by an ingenious arrangement were made to catch fire one from the other, so that by simply applying a light to one of the burners the whole ten thousand were ignited with great rapidity, and the entire structure, some eighty feet in height, appeared in a few seconds as if it were a solid mass of flame, thus presenting an exceedingly grand appearance. The illumination was very successful when tried on the previous night; the next night, however, one of the officials in command insisted, contrary to the advice of the gas engineer, upon letting off some fireworks from the wooden stage, before the illumination took place, the result of which was that the vast structure was burned to the ground before the gas was turned on. A report was circulated that the fire was caused by the gas, and this unfortunately being generally believed, the progress of gas illumination received another serious check. Next year, however, the Guildhall was lighted with gas, the 9th of November being the day fixed for the first trial. Here, happily, everything was successful, and the new light on this occasion was loudly extolled, and from this time onwards the success of gas as an illuminating agent may be said to have been complete. In 1813 Westminster was lighted with gas; in the following year many of the old oil lamps in the streets were superseded by the new light, and in the year after that, as we have just seen, it made a highly successful *début* at Guildhall.

Its progress now, though still slow, was sure; the old oil street lamps in the metropolis were gradually supplanted by gas, and not many years afterwards its use as a source of light became common in the provinces. Thus its rate of progress became more rapid; everywhere, where men were gathered together in numbers sufficient to maintain gas-works, was the material made and used, and now it is a very small village indeed that does not possess the means of supplying its inhabitants with the wherewithal necessary for the production of the cheap, safe, clean, and brilliant gas-flame.

In considering the mode at present in use for the manufacture of this now all but indispensable material, coal gas, it is a point worthy of observation that the main part of the process whereby thousands of tons of coal are daily consumed, is essentially the same as that which Mr. Clayton employed when he heated a few chips of coal in a closed vessel by which to charge the bladder from which he burned the *spirit* for the amusement of his friends.

The operations carried out in the production of gas may be said to be two in number: (1) the distillation of the coal, and (2) the purification of the crude gas so produced.

The first operation, viz., the distillation, consists in heating the coal in closed red-hot iron or clay vessels, called retorts. We are all aware that if coal be heated to redness in the air a considerable amount of heat and light will result, and that the coal will speedily be burned away and reduced to ashes. We will not, however, by that process succeed in collecting any such material as coal gas. If, however, instead of heating the coal in the open air we heat it in a closed vessel, such as an iron bottle, we shall have a large quantity of combustible gas produced.

This operation, then—that is, heating the coal in closed vessels—constitutes the first process, or the distillation, as it is called, in the manufacture of gas.

A very simple and familiar experiment will fully illustrate this process of producing gas by the distillation of coal. Into the bowl of a common tobacco clay pipe are introduced a few chips of coal about the size of a pea. Upon the top of the coal a layer of clay is put, in order to protect the coal from the action of the air. This simple arrangement being completed, the bowl of the pipe thus charged is heated to dull redness by being placed in the centre of a common fire. In a few minutes distillation of the coal will commence. Smoke will issue from the stem of the pipe, and in a few seconds more this will be succeeded by gas, which, on the application of a light, will inflame, and burn with a bright yellow flame, which will continue as long as the supply of coal in the bowl of the pipe lasts.

In gas-works, instead of tobacco-pipes, huge iron or clay retorts are employed, in which are distilled several hundredweights of coal at each charge. These retorts are built into brickwork, and are heated to the requisite temperature by means of furnaces appropriately arranged. The retorts themselves are nothing more than plain cylindrical vessels, from six to eight feet long, by about eighteen inches in breadth, closed at one end and open at the other. To the open end is adjusted a nicely-fitting door, by means of which the orifice can be quickly and securely closed. Not far from the open end of the retort there is an opening in its upper side, into which an iron exit-pipe is fixed, which is for the purpose of carrying off the gas as it is produced in the retort. All being ready, the retort is heated by the furnace just mentioned until it is red-hot; the door is then opened, and the charge of coal—broken into pieces about the size of a man's closed hand—is introduced as rapidly as possible, and the door quickly closed. Distillation at once commences, and the gas so produced, having no other means of escape, passes up the exit pipe just referred to, and then into a large iron vessel, named the *hydraulic main*, where it deposits the greater part of the tar and the ammonia water, which are produced simultaneously with the gas, and which accompany it thus far in the process of manufacture.

After leaving the *hydraulic main*, the gas—now partially, but by no means perfectly, purified—passes on to an apparatus called the *condenser*. This consists of a series of iron pipes generally placed perpendicularly, so as to present as much surface as possible to the cooling action of the air. The gas by passing through this condenser is lowered considerably in temperature, by which treatment it is freed from the last traces of liquid impurity with which it may be contaminated. It is not yet, however, free from all contamination; it still contains a certain amount of sulphur, present in the form of two compounds of that element, known to chemists as sulphuretted hydrogen and carbon disulphide. To remove these highly objectionable substances the gas is first passed through an apparatus called the *scrubber*. Here it is made to ascend through a falling shower of water, which removes in great part the compounds soluble in that liquid.

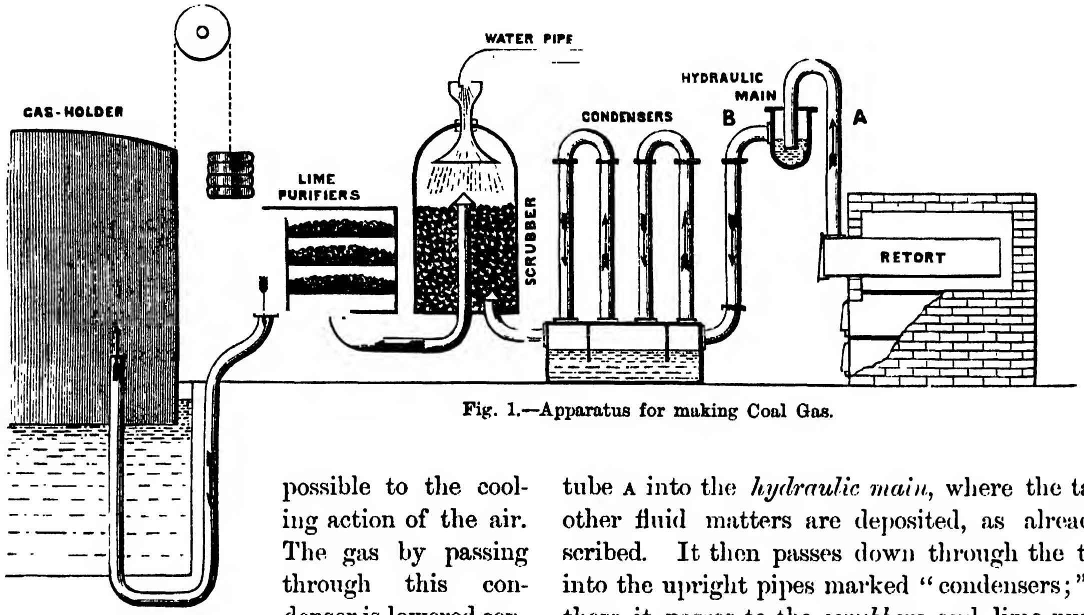

Fig. 1.—Apparatus for making Coal Gas.

The gas, however, is not yet pure enough for use, and to effect its final purification it is passed through what is known as the lime purifier. This consists essentially of a large air-tight vessel, in which are placed a number of trays filled with slaked lime. The gas is thus brought in contact with a very large surface of lime, by the action of which it is freed from the remaining sulphur impurities, and being now fit for use, it is passed into the gas-holder, whence it is forced to the different points where it is to be consumed.

By reference to the illustration below (Fig. 1), which shows the arrangement of the different pieces of apparatus just described, no difficulty will be experienced in tracing the course of the gas from the point where it is generated in the retort to its final reception by the gas-holder. On the extreme right the retort, heated by the fire beneath, and properly charged with coal, is shown. The impure gas here produced passes up through the exit tube A into the *hydraulic main*, where the tar and other fluid matters are deposited, as already described. It then passes down through the tube B into the upright pipes marked "condensers;" from these it passes to the *scrubbers* and lime purifiers, and finally into the gas-holder, where it is stored for use.

Having now obtained our gas pure and ready for consumption, it seems meet that we should make ourselves acquainted with its composition and with the mode in which it acts as an illuminating agent.

Coal gas, as it is usually prepared, contains four or five elements, but of these only two are really useful. These two are—hydrogen, the properties and preparation of which have been already described,* and carbon, a familiar form of which is common wood charcoal.

These two substances have very different properties, and neither of them singly would make a good illuminating agent. In consequence, however, of one of them possessing, to a very marked extent, those peculiar properties in which the other is deficient, they, when in combination, constitute a substance which, as we know, fulfils this office admirably.

Coal gas being really and truly a gas, it is difficult at first for the non-chemical mind to conceive how such a substance as carbon or charcoal can enter into its composition. That it does contain this element, however, we can easily show by performing the very simple but convincing experiment of holding a cold white plate in a common gas-flame for a few seconds, when it will be blackened, or smoked as we say. This smoke is nothing more than a portion of the carbon which the gas contained, and which was deposited on the plate in consequence of our having cut off the supply of air necessary for its combustion, and so preventing its removal in the ordinary way. The presence of the hydrogen can also be shown by holding a cold *dry* glass, such as a tumbler, over a small gas-flame, when, in a few seconds, the interior surface of the glass will become covered with a thin film of dew or moisture. This film is water, and as we know that water is generated when hydrogen is burned, we have here a proof of the presence of that substance in the gas.

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* "Science for All," Vol. I., p. 279.

Next we have to consider the offices which these two substances, hydrogen and carbon, fulfil by their presence in coal gas. Hydrogen, as we have seen in a former paper, is a very inflammable gas. It burns very easily, but its flame, though possessing a very high temperature, gives very little light; so feeble, indeed, is it, that it can hardly be seen in broad daylight. Clearly, then, it would not do for illuminating purposes. The carbon, on the other hand, does not burn readily, but when it is heated up to a high temperature, such as that possessed by the hydrogen flame, it becomes incandescent, and gives off a great amount of light. When coal gas burns we may regard these two operations as taking place. The hydrogen being very inflammable, easily catches fire, and by the great heat which it produces in burning it raises the carbon to such a temperature that it becomes highly luminous, giving rise to the beautiful bright flame with which we are all so conversant.

With reference to the amount of light which is produced when coal gas is burned, this we find varies considerably according to the quality of gas which is being burned, and its quality depends to a certain extent upon the mode of manufacture, but much more on the nature of the coal from which the gas has been procured. Thus, the average quality of London gas, which is made principally from English coal, gives a light which is equal to about that shed by fifteen sperm candles, while Edinburgh gas, which is made from a very rich variety of coal found in Scotland, and known as *cannel coal*, gives a light which is nearly twice as strong as that obtained from London gas. This fact is expressed technically by saying that London gas is fifteen-candle gas, while that made in Edinburgh is thirty-candle gas. The rate at which gas is burned in making the trials necessary to determine its illuminating power is five cubic feet per hour, and the flame so produced is very accurately compared by means of suitable apparatus with the flame of a sperm candle burning at the rate of 120 grains per hour. So that when we say that a certain gas is of twenty-candle power, we mean to express the fact that the flame produced by burning this particular gas at the rate of five cubic feet per hour gives as much light as that which would be given off by twenty candles, each burning at the rate of 120 grains per hour.

In considering the uses of gas there can be no doubt whatever that the service it renders as an illuminating agent is by far the most important. It furnishes us with a source of light which is at once highly efficacious, extremely convenient, and, when properly used, perfectly safe. From nothing else with which we are acquainted can we obtain a light so handy and so cheap as that which we get from gas.

In 1879 the shareholders in some London gas companies were startled by a report to the effect that henceforth electricity was to be used as a source of light instead of gas. The report, however, was ill-founded: the electric light* has as yet not superseded gas to any great extent, and it may be safely added, probably never will, so long as coals remain as cheap as they are at present. Electricity being thus limited in its employment, there is nothing left which in point of efficacy can compete with coal-gas.

In the matter of convenience, also, gas stands unrivalled. What can be easier than turning a stopcock and applying a lighted taper? Although, with the view of simplifying even this simple operation, a stopcock has been invented which, by being turned, not only allows the gas to escape, but lights it also.

Finally, on the score of safety, few gaseous inflammables can compete successfully with gas. It is true that occasionally we hear of disastrous effects arising from explosions of gas; such results, however, spring almost invariably from gross carelessness. Gas, by itself, will not explode; it is only when it is mixed with a certain proportion of air that it becomes formidable as an explosive agent; and if, when an odour of gas is perceived in a house, the gas supply be stopped at the meter, and the windows and doors opened to allow what gas has accumulated to escape, *before* a light is made use of, no explosion can possibly take place. Instead, however, of this very simple precaution being adopted, we generally find that when gas proclaims its presence in a house the first step is to light a candle, and carry it into the apartment where the dangerous and highly explosive mixture of gas and air is lurking, with a result the nature of which we are but too well acquainted with.

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* See "Science for All," Vol. I., p. 44, for an account of this "Light of the Future."

Besides being useful as a source of light, coal gas is now very extensively employed as a heating agent, being almost universally used in chemical laboratories, and other scientific work-rooms for this purpose. It is also largely employed by different artificers as a ready and clean source of heat, and it is very frequently used to supply the heat necessary in cooking operations. It commends itself for all these purposes by its exceeding cleanliness, there being no smoke and no dust when it is employed as fuel. It is also valuable in so far as it is thoroughly under command—we light our gas-fire, and it is ready for use immediately, and when we require it no longer we can extinguish it at once and completely.

Besides, however, serving as a source of light and heat, gas is also used as a motive-power, being applied for this purpose through the medium of the highly ingenious gas-engine. To understand how these elegant machines perform work, we recall to our remembrance the great force which a mixture of gas and air exerts when it is exploded.

In the gas-engine this tremendous power, which in ordinary circumstances is exerted in wrecking our houses, is made to drive a piston from one end of a cylinder to the other. The piston being thus kept moving, communicates its motion to a crank on an axle on which a wheel is fixed, and thus a rotatory movement, which can be applied to drive any machine, is obtained. This engine, it will be noticed, requires neither fire, boiler, nor steam—a very great consideration, certainly, in the many situations where motive-power is required, but where, in consequence of limited accommodation, or for other reasons, the presence of a furnace and steam boiler is not desirable.

Very intimately connected with the subject of coal gas, though, perhaps, hardly forming a part of it, are the numerous and valuable by-products of this now most extensive manufacture.

The principal of these products are coke, ammonia, and gas tar, as it is called. The first, which constitutes the residue left in the retorts after the distillation of the coal is finished, is largely used as fuel. The second—the ammonia—which in a state of aqueous solution is separated from the gas along with a certain amount of tar, by the *hydraulic main*, is very valuable, selling at from £80 to £100 per ton. It constitutes the base of ammonia salts, sal volatile among others. The third by-product, the tar, is by far the most important. At first this substance was regarded as a nuisance; to touch it was to be defiled, and the sooner and more completely it was destroyed the better. The researches of modern chemistry, however, have shown this apparently unpromising material to be a perfect mine of wealth. To understand this, it is only necessary to call to mind the magnificent coal-tar or aniline colours, which as they are now being produced in almost every hue and every shade, are rapidly superseding the older forms of dyeing materials.

The aniline, from which the colours are produced, is made by a somewhat complicated process from the tar. The crude material, as it is received from the gas-works, is first of all submitted to distillation. By this treatment it yields what is known as naphtha. This naphtha, which is a useful material in itself, is also distilled, by which operation a very light volatile liquid known as benzol is obtained, which is also very useful, quite independently of the part it plays in the process of the manufacture of the coal-tar colours. This liquid is one of the most powerful solvents of greasy matters with which we are acquainted, and hence it is very useful for removing stains caused by grease or oil from such fabrics as would be damaged by the application of soap and water. It is in very general use for this purpose by those people who make a trade of cleaning kid gloves and other delicately-coloured articles of apparel.

The benzol being thus obtained, it is converted by the action of strong nitric acid into what is known as nitro-benzol—a substance possessing a very pleasant odour, closely resembling that of the essential oil of bitter almonds, and which is used by confectioners for the purpose of communicating an agreeable flavour to certain of their wares.

The nitro-benzol having been procured, it is submitted to the last operation, which consists in distilling it with weak acetic acid or vinegar and iron filings. By this operation aniline is procured, and from this the well-known colours are prepared.

Finally, when the tar is distilled until no more volatile matter is given off, there is left a black solid substance known in commerce as asphalte, and which is used extensively in the present day in house-building, and in the making of roads and pavements.

Thus by the simple distillation of coal we obtain—firstly, the all-important and almost indispensable substance, coal gas; secondly, ammonia, a most valuable product, and one of the greatest importance in modern agriculture; thirdly, coal-tar, from which, as we have just seen, we obtain the useful materials, naphtha, benzol, nitro-benzol, and aniline—the source of the coal-tar colours; and fourthly, asphalte, now so much used in house-building and road-making operations.

THE MINOR PLANETS.

By W. F. Denning, F.R.A.S.

THE chief planets of the solar system were found to revolve (long before the telescope revealed the smaller members of the series) at approximately regular distances from each other in the order of outward progression, and it was a fact incidentally referred to by Kepler, that this harmony of position was disturbed in the case of Mars and Jupiter, between which there came a great void in the interplanetary spaces. The celebrated "law" attributed to Bode (but which really had its origin in Professor Titius, of Wittenberg), by means of which the relative distances of the planets were aptly represented, pointed distinctly to the assumption that an unknown planet revolved in the wide interval separating Mars from Jupiter (Fig. 1). Taking the solar distance of Saturn (which was considered the most distant planet at the time of which we are speaking) at 100 parts, then the distance of Mercury is 4, of Venus 4 + 3 = 7, of the Earth 4 + 6 = 10, and of Mars 4 + 12 = 16, but from Mars we have to leap over a tremendous gap in the sequence of orbits before we come to Jupiter at 4 + 48 = 52. Midway in the interval we get 4 + 24 = 28, and here it seemed from the analogies of the law that a planet was wanting. In order to show the alleged correspondences let us take the numbers :—

0 3 6 12 24 48 96

which, counting from the second, exhibit an increase of double value at each step; adding 4 in every instance we have—

4 7 10 16 28 52 100

and these figures show a very remarkable coincidence with the actual planetary distances computed from observation (the Earth's distance being considered = 10) as follows :—

3·87 7·23 10·00 15·23
☿ ♀ ⊕ ♂
void 52·03 95·39
♃ ♄

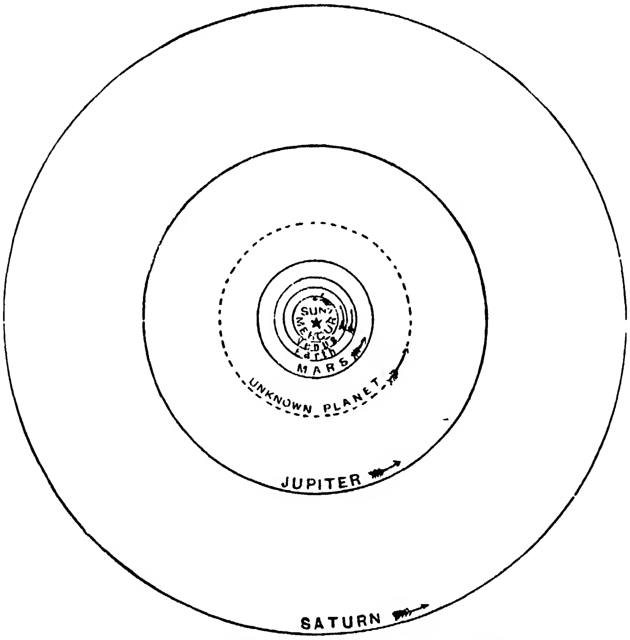

Fig. 1.—Relative Position of Planetary Orbits.

The dotted circle indicates the region where, in the void between Mars and Jupiter, a planet was supposed to exist before the detection of Ceres in 1801.

Those among our forefathers who reposed faith in universal laws or analogies as a basis of prediction must here have found an attractive subject for speculation. This law of Titius conformed with remarkable closeness to the relative distances of the planets, except in one instance, and this of so striking and distinct a nature as to lead directly to the inference that a large planet or series of planets remained undiscovered. Kepler wrote in the introduction to one of his works :—"I have become bolder, and now place a new planet between Jupiter and Mars, as well as another between

Venus and Mercury; probably it is the extreme smallness of both which has caused them to remain unseen." Titius himself, speaking of the great vacancy between Mars and Jupiter, expressed his conviction that "we must not doubt that it is occupied; it may be by the hitherto undiscovered satellites of Mars, or perhaps Jupiter may have additional satellites that have never been seen by any telescope."

The so-called law of Bode in a modified form was applied by Wurm of Leonberg, who, adopting 387 as the distance of Mercury, 680 as that of Venus, and 1,000 that of the Earth, derived the following numbers:—

			True distances.
Mercury . . .	387	...	387
Venus	387 + 293 =	680 . .	723
The Earth . .	387 + 2 × 293 =	973 . .	1·000
Mars	387 + 4 × 293 =	1·559 . .	1·523
Unknown Planet	387 + 8 × 293 =	2·731 . .	—
Jupiter . . .	387 + 16 × 293 =	5·075 . .	5·203
Saturn . . .	387 + 32 × 293 =	9·763 . .	9·539
Uranus . . .	387 + 64 × 293 =	19·139 . .	19·182

Though these figures present a very close approximation, they do not exactly coincide, and thus the alleged agreements were sometimes ridiculed as unworthy of more importance than should be attached to a purely accidental correspondence of numbers. But many remained dissatisfied; they saw the wide breach in the successive folds of the planetary orbits, and remembering the harmony and regularity with which the whole mechanism of the solar system had been devised, they ventured yet to predict the ultimate discovery of a planet which should restore the continuity of the series. True, the ancients had never seen the vestige of any such body, though they had pursued observations with a far-seeing vigilance, and had even detected the fugitive Mercury. Obviously, therefore, if an unknown planet revolved between Mars and Jupiter it must be of extremely diminutive proportions, shining, in fact, with such feebleness as to be utterly beyond the range of human vision.

Towards the end of the eighteenth century a great impetus was given to observational astronomy by the eminently successful labours of William Herschel and his contemporaries, Shröter, Messier, and Olbers. The time had evidently come when something of an effort must be made towards the practical solution of the question. The suspected planet must be searched for in a systematic way, and by a corps of experienced observers. Accordingly, in 1800, an association was formed for the special purpose of exploring the zodiacal constellations, and critically examining the smaller stars there which might by appearance or change of position give indications of a planetary nature. The work was distributed amongst twenty-four observers; each had one hour of right ascension (equivalent to 15 degrees) apportioned him, in which all the telescopic stars were to be subjected to a rigid scrutiny. Begun with such excellent method, and pursued with unabating energy, the search could not long prove fruitless. On January 1st, 1801, Professor Piazzi, of Palermo, discovered a faint stellar object in Taurus, which could not be identified with any star recorded in the catalogues. Observing it again on the following night, and finding that its exact position with regard to the neighbouring stars had certainly changed, there was no longer any doubt as to its real planetary nature, though Piazzi at first mistook it for a comet on account of the ill-defined nebulous light in which it seemed enveloped. He continued to observe it until the 12th of February ensuing, when, however, he fell ill, and an abrupt termination was put to his observations. The new planet was then lost for a time, but Dr. Olbers, of Bremen, recovered it after diligent observations, and its orbit was approximately computed from the available data obtained by him and Piazzi. The period assigned for its revolution was 1,652 days, at a mean distance from the sun of 2·735, the earth's distance being considered = 1. The new planet, for such it was incontestably proved to be, was named Ceres, and to those who had advocated the existence of such a body between Mars and Jupiter, the event afforded the most signal gratification, for nothing could be closer than the agreement between its predicted position and that actually derived from calculation. The law of Titius and Bode, as corrected by Wurm, indicated the place of the planet at 2·731; it was really found at 2·735, which is almost absolutely coincident. The great void separating Mars from Jupiter had disappeared, for exactly at the place where the analogies of the planetary distances had shown a planet to be wanting, one was found, and of such small dimensions that no wonder the expectant gaze of the ancient astronomers had been turned to it in vain.

The discovery of Ceres was the prelude to other important discoveries of a similar nature. Dr. Olbers, early in 1802, had been carefully noting the small stars of Virgo, and in March of that year, while awaiting the re-apparition of Ceres after its conjunction with the sun, detected a faint body in a position which he could not reconcile with his former observations. This eventually proved to be a new planet which, on full investigation, displayed many points of similarity with that of Ceres, for its orbit and period were nearly identical, and it exhibited the same nebulous appearance and small proportions as that planet.

The assiduity of the observers was not relaxed on the discovery of these planets, which, indeed, caused them to redouble their efforts, so that on September 1st, 1804, a third was found, and on March 29th, 1807, a fourth. The former was detected by Professor Harding, of Lilienthal, Germany, and was named Juno. The latter was found by Dr. Olbers, and called Vesta, and was decidedly brighter than either of the others. When near opposition with the sun, this planet is just perceptible to the naked eye, shining like a star of about the sixth magnitude. Thus four planets had been added to the known members of the solar system by the diligence with which the observations had been pursued; but though the work was continued until 1816, no further discoveries were announced, and the search was finally given up. The results which had been achieved fully compensated for the labour involved. Four minor planets, forming a new order of bodies, had been detected between the orbits of Mars and Jupiter. Their elements, computed from the most recent data, are as follows:—

Planet.	Discovered.	Distance (⊕ = 1).	Period Days.	Diameter Miles.	Star Mag.
Ceres . .	1801, Jan. 1	2·767	1681	227	7·7
Pallas . .	1802, Mar. 28	2·769	1683	172	8·0
Juno . .	1804, Sept. 1	2·671	1594	112	8·5
Vesta . .	1807, Mar. 29	2·362	1325	228	6·6

Sir William Herschel gave the name of asteroids to this new group of bodies, but they are sometimes more appropriately called planetoids, and of late years it is superseded by the term "minor planets," which is becoming universally adopted as the most suitable title for this numerous and rapidly-increasing class of bodies.

Upon the discovery of Ceres and Pallas, Olbers was led to a bold conjecture as to their origin. It was found that their two orbits nearly intersected, that Ceres in her ascending node passed near Pallas, and he inferred from this that the two bodies might be the disrupted fragments of a large planet previously revolving in the broad interval which separates Mars and Jupiter, but which became shattered into pieces by some great natural calamity, and he further predicted the discovery "in the same region of many more such fragments." Were they the disintegrated materials of one mass, he concluded that they must formerly have taken their departure from the same region, and their motions should exhibit "two common points of re-union, or two nodes in opposite parts of the heavens through which all the planetary fragments must sooner or later pass." On further investigation he found the position of these nodes to be in Virgo and Cetus, and it afforded singular evidence in favour of his remarkable conjecture when the planet Juno was afterwards discovered in Cetus, and Vesta in Virgo.

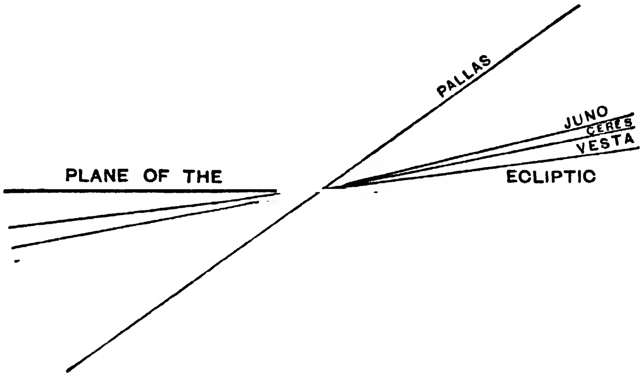

Fig. 2. –Diagram exhibiting the Relative Orbital Inclinations of the Chief Minor Planets.

It must be admitted that the diminutive proportions of the new bodies, and the fact that they revolved at nearly similar distances from the sun in mutually intersecting orbits, aptly suggested the thesis of a close relationship, and pointed distinctly to the assumption that they owed their origin to the same source. Evidently they formed a special group of bodies with some anomalous features which sufficiently indicated their exceptional character, and signified that they could hardly be classed in the same category as the major planets of the solar system, which were vastly superior in size, and showed a totally different arrangement of orbits. The minor planets were found to revolve in singularly eccentric paths, inclined to the plane of the ecliptic at greater angles than any of the major planets (Fig. 2). Thus the inclination of Ceres is 10° 36′; of Pallas, 34° 43′; of Juno, 13° 1′; and of Vesta, 7° 8′; whereas that of Mars is only 1° 51′, and of Jupiter, 1° 19′. The orbit of Pallas is, in fact, inclined at such a considerable angle that the planet may extend its excursions to some distance on either side of the ecliptic, and these eccentricities of motion have been held to favour Olbers' theory of a fractured planet. Such a theory, though incapable of being demonstrated, and inferring, as it does, the occurrence at a far remote epoch of a stupendous phenomenon in the planetary spaces, is yet not altogether untenable when we consider the facts which have formed the basis of such an hypothesis, and the satisfactory explanation it gives to many curious results of observation. We are wholly ignorant of the vicissitudes to which the planets have been subject during the successive stages of their existence. At an early period of its creation, and before its mass had been tempered into solid coherence, the intra-Jovian planet may have collapsed under the influence of divellent forces acting upon it from within, and its fragments become distributed in a variety of new orbital paths around the sun.* But we are not upholding this theory of a fractured planet, though it should not be too hastily disapproved. Many wonderful changes have occurred amongst the celestial bodies, and the freaks of nature are sometimes such as not only startle the mind, but defy the most able attempts at explanation. Stars of unprecedented lustre have suddenly appeared in the heavens and remained visible several months, as for example, Tycho Brahe's star in Cassiopeia (1572). Comets have been seen to divide into separate parts, like that of Biela, in 1845. The spots on the sun have presented strange phenomena. Dr. Wollaston once saw a solar spot burst to pieces while he was observing it. The appearance was like that of a piece of ice when dashed on a frozen pond, which breaks into atoms, and slides on the surface in various directions. In 1859, a remarkable event in solar physics was witnessed by two observers, who, while examining a large group of spots, saw "two patches of intensely bright, white light break out in front of the spots and remain visible for about five minutes, during which time they traversed a space of about 33,700 miles." Meteoric stones, of huge dimensions, have fallen upon the earth after traversing space with planetary velocity, and these vagaries of nature are mentioned in contradistinction to the harmony and regularity of which we are accustomed to hear so much in relation to the celestial orbs. It is certain many instances could be cited of anomalous phenomena, suggesting an immediate origin in a disruption of planetary materials, and it would be unfair to negative a theory because it is hardly consonant with our views of the pleasant working of nature's laws. At a primitive epoch in the history of the planets we cannot say what stupendous forces were operating in the general chaos of disorder, or what destructive agencies were directed against the infantile forms of the planetary spheres. As they are telescopically displayed to us at the present time, we are enabled to trace out many interesting facts of their appearances and motions; but a deep mystery hangs over their early history, and we know nothing more than that they were originally designed by an Omnipotent Creator, and by Him directed upon their courses.

Subsequent to the detection of the four minor planets—Ceres, Pallas, Juno, and Vesta—a remarkable lull occurred in the progress of planetary discoveries. There were absolutely no additions to our knowledge during nearly the forty years that ensued. In the meantime improved star maps had been published, which, containing the smaller magnitudes, were of great practical utility in the search for minute planets. The Berlin charts, including stars up to the 9th or 10th magnitude, situated within 15° of the equator, superseded the less comprehensive charts of former observers, and though the twenty-four maps, of which they consisted, were not finally completed till 1859, a portion of them had been issued many years previously, and Herr Hencke, an amateur astronomer, at Driessen, in Prussia, availed himself of their aid in a renewed search for new planets. For a long time he was unsuccessful. Evidently the brighter planets had already been sought out, and those remaining were of such minute character as to readily elude the most vigilant eye. At length, however, on the night of December 8, 1845, he found a suspicious object which he had not seen before in the same position, and which could not be reconciled with any star marked in his charts. This eventually proved to be another minor planet, and he followed up his success with a similar discovery on July 1, 1847. They were very faint objects, not brighter than ninth magnitude stars when first seen, and required a powerful glass to render their true character apparent.

These planets were the *avant-coureurs* of the host of similar bodies which have been detected since that epoch, and which is rapidly increasing every year. No less than 212 have been discovered since Hencke announced his first success in 1845, and judging from the annual rate of increase the number seems likely to extend itself indefinitely.* In 1877, ten were discovered; in 1878, twelve; and in 1879 no less than twenty, which far exceeds the number found in any previous year. Six of them were detected in the same month (October), and the majority of these discoveries are due to Dr. C. H. F. Peters,† at Clinton, U.S., and to Signor Palisa, at Pola; for of the forty-two new planets which have been detected during the three years mentioned, they each discovered fourteen, leaving only one-third of the aggregate number to be distributed amongst other observers.

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* Professor Kirkwood, of Indiana, attempted the theoretical reconstruction of the dissevered planet from its existing fragments, and built up in this manner an hypothetical planet of no mean dimensions, giving it a diameter of more than 4,320 miles, and a rotation on its axis of 57½ hours, which, therefore, must have been performed at a very sluggish rate. (See British Association Report for 1850, p. xxxv.)

Fig. 3.—The Zone of Minor Planets between Mars and Jupiter [illegible]s more of these bodies than have been hitherto discovered, but fewer than we are warranted in assuming to exist.

It was found necessary with the rapid increase in the list of minor planets, and the difficulty of finding suitable names, to number them progressively according to date of discovery, so that these bodies are distinguished both by a number and a name, and it must be admitted that this form of nomenclature affords a great facility of reference. Let us take the first seven planets discovered in 1879, which stand in our catalogues as follows:—

No. of Planet	Name of Planet.	Date of Discovery, 1879.	Discoverer.	Mean Distance. ⊕ = 1
192	Nausicaa	February 17	Palisa at Pola	2·401
193	Ambrosia	February 28	Coggia ,, Marseilles	2·626
194	Procne	March 21	Peters ,, Clinton, U.S.	2·653
195	Eurycleia	April 22	Palisa ,, Pola	2.874
196	Philomela	May 17	Peters ,, Clinton, U.S.	3·082
197	Arete	May 21	Palisa ,, Pola	2·753
198	Ampella	June 13	Borrelly,, Marseilles	2·479

The necessity of affixing numbers to these bodies will be apparent to any one who reflects on the difficulty of referring to the individual members of the series without some such guide; were the name only given, the eye must sometimes run through the whole list before alighting upon the particular planet required.

Comparatively few of these bodies have been discovered in England; indeed, observers in this country treat the subject with apathy. Thus we need not be surprised that foreign astronomers have wholly monopolised the field of planetary and cometary discovery for many years, and to them must be awarded whatever credit is attached to such valuable and original researches. Mr. J. R. Hind, observing at London, found ten of these bodies during the years 1847–54. Mr. Pogson at Oxford added three others in 1856–7; and Mr. Graham at Markree, Ireland, had found one in 1848; but these appear to be the only discoveries of the kind of which we can boast. The first intimation we usually receive of the detection of new planets or comets comes in the form of telegraphic messages from the observatories at Clinton, Marseilles, or Pola.

M. Goldschmidt at Paris was one of the foremost discoverers of minor planets, and he owed his success entirely to the zeal with which he pursued the work. His observations were conducted from the balcony of his apartment in the Rue de Seine, Paris, and with telescopes of small aperture mounted on ordinary stands. His indefatigable energy, however, more than compensated for his instrumental defects, and thus he added fourteen planets—two of which were detected on the same night, viz., Sept. 19, 1857—to the known members of our system.

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* Chambers ("Descriptive Astronomy," 1st Edition, 1867, p. 101) remarks, that "for the present at least the number of new planets will not materially be augmented, and for this reason—the want of telescopes suitable and available for looking after them. All the brighter ones have evidently been found, and, speaking generally each new one is fainter than its predecessor." This prediction has been fully negatived by our experiences of the last few years, which have been unusually prolific of such discoveries, and seeing that we may even now infer the existence of a multitude of unknown planets of about the twelfth or thirteenth magnitudes, we have every reason to believe that the stream of discovery will run on with unabated strength in future years.

† His first planet was found on May 29th, 1861, and the aggregate number of his discoveries now reach forty-four, which exceeds that of any other observer.

Amongst other astronomers the names of those whose success has been most conspicuous in this department, are Dr. Luther at Bilk, De Gasparis at Naples, and Mr. Watson at Ann Arbor, U.S.

The annual rate of discovery since 1845 has been six. Fully one-half of the aggregate number (260) of such discoveries has been made during the last ten years. Those more recently found are of extremely faint character, and observable only in first-class instruments, whence it is fair to conclude that all which have hitherto escaped detection are fainter still, and form a more numerous class than those which are already included in our catalogues. Their orbits are without exception placed between Mars and Jupiter (Fig. 3), and they circulate around the sun in a zone extending from Medusa (149), the nearest to the sun, to Hilda (153), the farthest from the sun, the mean distances being 2·132 and 3·950 respectively, which corresponds to about 195,000,000 and 361,000,000 miles, and gives the breadth of the zone as 166,000,000 miles.

But it should be mentioned that Hilda is situated far outside any other minor planet, for previously to her discovery by Palisa at Pola, on Nov. 2, 1875, the most distant were Cybele (65), Hermione (121), Sylvia (87), and Camilla (107), whose mean distances are 3·43, 3·46, 3·49, and 3·56 respectively. Comparing the sidereal period of Hilda with that of Medusa we find that the former is performed in 2,868 days (nearly 8 years), while the latter slightly exceeds three years.

The thickest region of the zone seems to be at a mean distance of from 2·600 to 2·800, or 247,000,000 miles, and exactly where, from the analogies of Bode's law, a planet was wanting. In fact, the void between Mars and Jupiter, which so forcibly impressed itself upon the old astronomers (and led them to predict the existence of a planet there), has been filled up, in a manner unexpected, by a multitude of diminutive orbs, whose numbers seem illimitable. How long their discovery will go on unchecked, or how the inevitable confusion of dealing with such a large number of bodies, and distinguishing them from each other, will be avoided, no one can say at present. There will be considerable difficulty in predicting their positions and in verifying them by instrumental observation, according to the plan followed at the observatories of Greenwich and Paris during the last few years. It does not seem improbable that several of the new planets may be finally lost, unless the national observatories are able to keep pace with the increasing demand for corrective and corroborative observations, and apply them to the accurate determination of the orbital elements in each case.

The orbits of several of the minor planets are very eccentric—that is to say, they deviate considerably from a circular form. In the case of Pallas and Juno this is presented in an extreme degree, the eccentricity amounting to 0·240 and 0·256 respectively, and it is even more striking in some of the smaller planets of the group. Thus, for Polyhymnia (33) it amounts to 0·337, and this is exceeded by Æthra (132), and several others, so that the orbits are ellipses of different eccentricities, which must obviously cross each other, and intermingle in the most complicated fashion. Indeed, the possibility of collision between certain of the minor planets has been sometimes pointed out, though the chances of such a catastrophe are lessened by the fact that they move in a common direction from west to east around the sun, in accordance with the motions of the major planets of the solar system.

The telescope has hitherto failed to reveal any markings upon the surfaces of the minor planets, indeed, these bodies are quite beyond the reach of such examinations in detail. Moreover, they are apparently surrounded in nebulous envelopes, which wholly prevent such investigations, for their discs are rarely seen with sharply-defined outlines. Coupling with this their extremely small dimensions, we can at once appreciate the difficulty of grappling with the subject. On the assumption that light is equally reflected from the surfaces of these bodies, Mr. Stone, in 1867, calculated the approximate diameters of seventy-one, which he found to range from 17 to 214 miles. The smallest was Echo (60). Such exceedingly minute objects, placed at enormous distances from the earth, must obviously defy the most rigorous attempts at scrutiny, and we can safely predict, that until telescopic power is yet further increased, nothing will be distinguished of the physical aspect of their surfaces.

Vesta is sometimes seen when near her opposition to the sun, by the naked eye, shining as a star of the sixth magnitude, and Ceres and Pallas are occasionally observed without telescopic aid; but as a rule these small bodies are perceptible only in glasses, and nothing but the finest instruments will display their planetary character. The smallest members of the group are to be identified from faint stars only by their motion.

The theory of a shattered planet formerly propounded by Dr. Olbers has not received confirmation by the large additions which have been made to the number of minor planets in recent years, for on careful investigation, the mutual relations of their orbits are found to be insufficiently close to distinctly favour the hypothesis. Indeed, in many cases the assumption would appear to be negatived by the facts, so that the question must still be regarded as *sub judice* amongst astronomers, and it is difficult to see how it can ever receive a final settlement.

SHARKS AND STURGEONS.

By F. Jeffrey Bell, M.A., F.R.M.S.,

Professor of Comparative Anatomy in King's College, London.

THE student of zoology is, above all things, the student of the History of Animals, and, just as every historian, he has not only to study the habits and economy of every group, but he has further to trace the means by which they have arrived at their present condition. Two principal methods are well recognised; one is the study of Palæontology, from which we learn the characters of animals in the past, the other is the study of Embryology, which shows us, more or less distinctly, what are the varied stages through which any given animal has passed in the person of his ancestors.

But there is yet another mode which is full of instruction, and which was indeed for many ages the only mode in which the history of animals was ever studied—the method of comparison. For the present, indeed, Comparative Anatomy is less fashionable than Palæontology or Embryology, but its value is never denied, and can never be too highly estimated; for the purposes of popular instruction it is still unrivalled, for it is not given to all of us to have been able to trace step by step the development of even so accessible an object as a hen's egg, and the study of fossil remains requires a considerable acquaintance with more recent forms. This being so, we purpose on the present occasion to illustrate the history of the vertebrata, or backboned animals, by a study of the arrangements which are found to obtain in some of the more lowly forms. Knowing the simpler, it will be easier henceforward to understand the more complex and more highly developed.

When we look upon the group of fishes as a whole, and understand by that term all the different forms which have ordinarily been grouped under it by the zoologist, we find that there is one, which may, in a moment, be completely separated off from all the rest; this is the little lancelet (*Amphioxus*, Fig. 1), in which there is no considerable enlargement of the spinal cord to form a *brain*, no special covering of bones to form a brain-case, no ear as in other vertebrata, and no special modification of part of the great blood-vessel to form a *central* heart. This creature may be briefly said to be *acraniate* (without a cranium or brain-case), and be thereby at once distinguished from all other Fishes, and all the rest of the vertebrata, which may be spoken of as being *craniote*, or, in familiar language, "skulled."

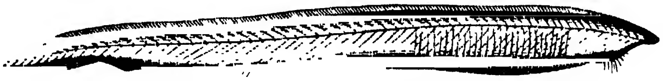

Fig. 1.—The Lancelet (*Amphioxus*).

Next, among forms ordinarily spoken of as being fishes, we come to what are popularly known as the round-mouths—the hag and the lamprey—but these may be at once set aside in so far as they do at any rate differ from the fishes proper in having no jaw-apparatus distinctly developed; they are the "jawless" fishes. Full of instruction as are the peculiar arrangements of their mouth, it is beyond the scope of the present paper to enter upon it.

Having, then, disposed of these *Acrania* and *Cyclostomata*, we come to the groups which all zoologists are agreed upon in regarding as fishes. When we examine them carefully we see that they fall into two distinct divisions; in one, the bony fishes (*Teleostei*), every imaginable possibility and alteration of structure seem to have been taken advantage of; flying fishes, climbing fishes, forms like the eel, almost limbless, are here developed in almost endless variety. Among the other group considerable differences are apparent enough, but that which rather strikes the careful observer, who is intent upon seeing their relations to higher forms, is the indication given, now by one, now by another, of an approximation to that more complex standard which is familiar enough to all of us in the organisation of the frog.* These we will shortly test in some detail; as an introduction we will only say that among these forms only do we find the fishes of the earlier epochs of the world's history, and among them only is it that we see in full distinctness most of the leading points of the vertebrate characteristics; the bony fishes lose these as they gain other advantages. But the sharks, the sturgeons, and so on proclaim continually their ancient derivation, and, as evolutionists would say, their closer affinity to the line of ancestry which, leading through the frogs, has culminated in the snake, the crocodile, and the eagle on the one hand, and on the other in the horse, the whale, and the highest mammals. It is to this group that Dr. Günther has applied the term *Palæichthyes* or Old Fishes.

Before, however, the reader is able to form his judgment on the statements here made, it will be necessary to put him in possession of a definite statement of anatomical facts, and for this purpose we will take the not infrequent Dog-fish (Fig. 2).

The body is elongated, the tail long and better developed below than above; the head appears to be disproportionately large; behind it is a number of elongated narrow slits, and just behind these, which are the gill-slits, there is on either side a large flapper-like *fin*. When the skin is touched it is found to be not soft and slimy, as it is in a number of bony fishes, but to be roughened with a number of projecting spinelets; later on we shall find that these spinelets are almost exactly similar in character to the teeth which we shall find in the jaw. On the ventral surface towards the hinder end there is an orifice which communicates with different organs within the body.

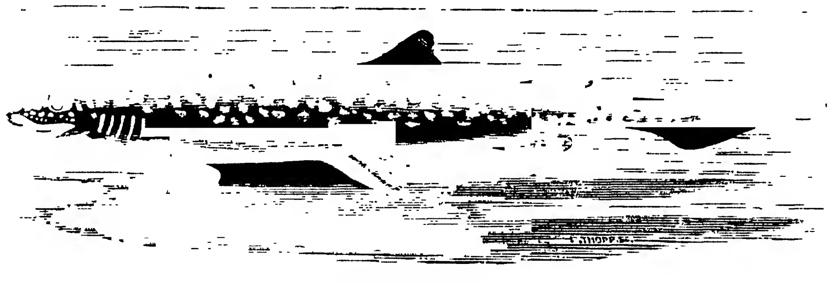

Fig. 2.—Dog-fish.

The elongated form, the strong fins, the powerful tail are the locomotive organs of this rapacious creature. The gill-slits have a higher interest than that of mere organs by means of which the water, which serves as the carrier of oxygen to the blood, escapes to the exterior, for these slits have in earlier life delicate processes projecting from them, which are external gills—organs which, in fact, go to the water instead of waiting for the water to come to them, and organs, too, which are to be found in the young tadpole, and are permanently retained throughout life by some of the near zoological allies of the frog and toad. Nor is this all; in the developing chick, at about the third day, there are to be seen four clefts on either side of the throat, bordered on either edge by a projecting fold (*visceral* fold), of which, therefore, there come to be five; the foremost fold becomes developed into the jaws, the foremost cleft forms the passage of the ear; the other clefts disappear in the course of development, but two of the folds have a permanent duty and an interesting history (Vol. II., p. 197). These we shall not follow now, if for no other reason than that we may, by this bare recital, direct more undivided attention to the remarkable fact that in an animal so apparently unlike a fish, there are, at an early period of life, structural arrangements which much more easily remind us of a shark than of a flying air-breathing bird. Much the same general account might be given of any mammal.

Now we come to the spinelets on the skin, which we have promised to show as existing also in the mouth, where, being larger and better developed, as well as more regularly arranged, they have been justly enough distinguished as *teeth*: as the researches of two workers, independent of one another—the one in Germany and the other in England—have shown, the spines on the skin and the teeth in the mouth, when ground down and examined, have often almost exactly the same structure. The mode in which the difference in external appearance has been brought about will be best understood by a reference to a young dog-fish just before its time of being hatched. The membrane (mucous membrane) lining the mouth is directly continuous with the outer skin, and as there is as yet no distinct underlip, it is quite easy to see how absolutely the two pass one into the other; indeed, the difference between them is local, and, from a general point of view, altogether artificial. Next, then, the spine-bearing skin is continuous with a mucous membrane bearing spines which would be altogether similar were they not a little larger. As the dog-fish grows the difference in size and number becomes more and more marked, but the reason of this is by no means difficult to understand. We all know that if we continually carry heavy weights, if we regularly use dumb bells, or if, by any means whatsoever, we throw a greater amount of work on any part of our bodies, that part increases in size—witness the arms of the oarsman, or the calves of a pedestrian. The proximate cause of this marked increase in size does not, of course, depend on our using these muscles more, for all work, all exercise of energy, is in the first place accompanied by loss of tissue or material; but in the animal world, just as elsewhere—in the banking or trading world, for example—it is true that to him that hath shall be given, *when he makes use of what he has;* in the one case just as much as in the other, there comes an increase in the circulation, and the blood that circulates in the muscle brings with it a rich supply of nutriment to the parts engaged; these parts then grow or increase in bulk. This can easily enough be applied to what happens in the jaw of the dog-fish (Fig. 3); the spinelets inside the mouth are continually brought to bear on the food that is taken in, and they, in consequence of this, their extra duty, increase in size, and in time in number. We may parallel this history by referring to what happened in ourselves when we chafed our god-mothers' gift of coral, with the result of directing to our toothless gums a greater flow of blood; and we may link it with that curious fact that, not till the teeth have begun to appear do the salivary glands at the sides of the mouth begin to take on their especial function. As to these last, and their rich supply of blood, sufficient has been said in earlier papers (Vol. III., p. 306, and Vol. IV., p. 88).

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* "Science for All," Vol. I., p. 81; Vol. III., p. 145.

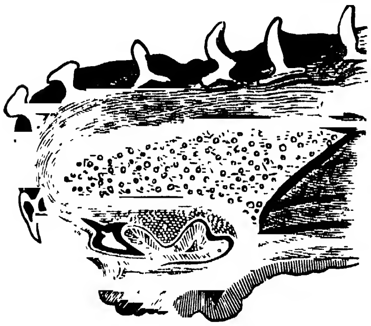

Fig. 3.—Lower Jaw of Young Dog-fish. (*After Tomes.*)

The teeth and the spines make up the outer skeleton of the dog-fish. We must now pass to its *internal* skeleton. Here we shall have very shortly to consider the brain-case, the axial skeleton which runs along the middle line of the back of the body; as to the fins (or limbs) which are attached at the sides, we must refer to what was said on the hand (Vol. II., p. 261). All these parts are bony in most of the vertebrata, but the dog-fish and its allies are very interesting, because they possess no bone at all. The greater part of every skeleton is first, in its broad outlines, laid down in a softer and more elastic material, which is known as cartilage. This tissue is retained by the sharks and rays during the whole of their life, and it is because of this that they are ordinarily known as cartilaginous fishes. The tissue may, and indeed does, become hardened and strengthened by the deposit on its surface of salts of lime, but it never becomes converted into true bone.

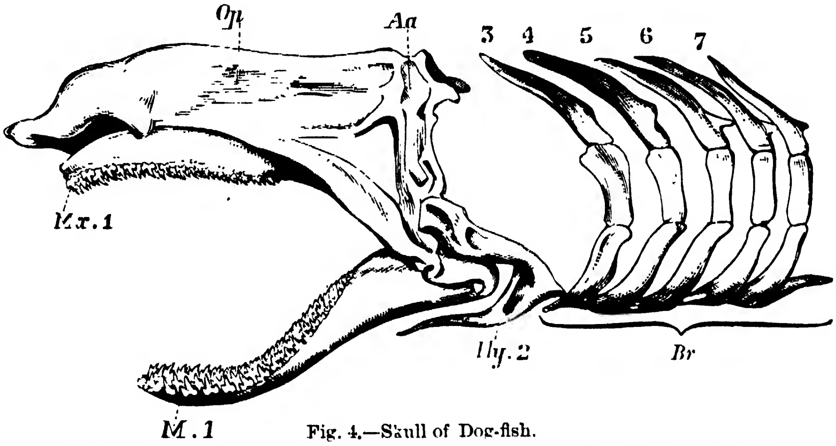

Fig. 4.—Skull of Dog-fish.

Mx. 1, Upper Jaw; *M.* 1, Lower Jaw; *Op* Eye-cavity, *Aa*, Ear-cavity; *Hy* 2, Hyoid Arch; *Br.* 3, 4, 5, 6, 7, Branchial Arches.

The skull or brain-case (Fig. 4) can hardly be said to be a particularly beautiful structure, as looked on by the uneducated eye. Attached behind to the vertebral column, it is continued forward into a more or less projecting snout. On either side there is a large cavity for the eye (*Op*), and at this, the optic region, it is narrower than it is in front. Above the eye there is a projecting ridge, and behind this there is the projecting wall of the cavity of the ear (*Aa*). The jaw parts are—and this is a most interesting point—very loosely attached to the brain-case proper. By three chief ligaments the upper jaw (*Mx.* 1), which is much broader behind than in front, is attached to the different parts of the brain-case. The lower jaw (*M.* 1) is very deep behind, where it is connected with the upper jaw, and gradually narrows as it passes forwards. Posteriorly it is loosely attached to the back of the brain-case by an arrangement of cartilaginous pieces. On the present occasion we do not intend to take the reader through the details of the skull-parts; for the moment it is sufficient to direct attention to the loose connection that there is between the brain-case and the jaws.

The significance of all this will be seen in a moment when we have learnt to know a little of the cartilaginous arches which support the gills. To these let us now turn, having first of all stated that a bar of cartilage joining the back part of the skull to the lower jaw extends outwards in a horizontal direction.

Connecting the skull with the jaws is a bar of outwardly-projecting, horizontally-directed cartilage (*Hy.* 2). Behind this there lie several bars of cartilage (*Br.*), similarly encrusted externally with a deposit of carbonate of lime and other salts. These are jointed and free at their outer end; at their inner they are connected with a piece of cartilage, originally also jointed, which lies in the median ventral line. These are the cartilaginous supports of the gills, and the boundaries of the gill-clefts.

Now comes the question, what relation have these arches to the jaw in front of them and to the bar of cartilage running from the hinder region of the skull to the point where the lower and upper jaws pass into one another? Well, the relation is no more important than this—that the first two, as here considered, have become greatly modified, while the hinder ones have retained very much their original relations. The first, or *mandibular* arch, has some such history as this:—Very early in life it develops an enormous process, which projects forwards and bounds the mouth on either side. Then it grows forwards, and becomes not only gradually connected with its fellow of the opposite side, but, thanks to the development of the connecting ligaments, of which we have already spoken, it comes into a more close relation to the brain-case. Shortly after this, the arch undergoes a distinct jointing, and the upper jaw and the lower jaw cartilages begin to be separated; the outlines of the upper and lower jaw are, in fine, already beginning to be filled in. There is here no need to make matters more difficult by following the history of the second, or *hyoid*, arch; enough has been said to show that they are parts which essentially resemble those which follow them in a serial fashion, and that they only differ by such characters as increase in size or diminution in apparent importance from those gill-arches which come after them; and which have, throughout life, the not unimportant function of supporting the pouches of membrane to which blood is sent directly from the heart, to undergo the necessary process of refreshment, by coming into contact with a stream of water containing a supply of fresh oxygen.

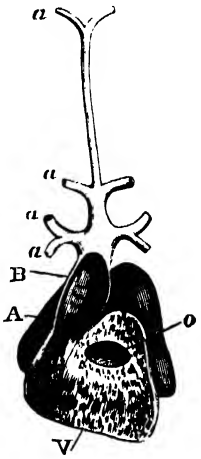

Fig. 5.—Heart of Squatina. (*After Gegenbaur.*)

A, Auricle; B, Arterial Cone; *aaa*, Branchial Arteries; *o*, Orifice of the Ventricle (V)

Let us, then, now turn to the *circulatory system* of the dog-fish. Even those of us whose hearts do not trouble them know that two pairs of cavities are to be found in the heart of man: two cavities, which receive blood from the body or from the lungs, and which are known as *auricles;* and two cavities, which by their contraction drive this blood to the lungs or through the body—the *ventricles.* A pair of each may each be known as *pulmonary*, or as *systemic* (supplying the general system of the organism); but the dog-fish has no pulmonary division of the heart (Fig. 5). There is in it only one auricle and only one ventricle, and these are systemic. One receives the blood from the body, the other drives the blood, vitiated by contact with the tissues, to the gills, and thence the blood, refreshed by new oxygen, goes direct to the general system of the body. There are certain complications, and there are, as the figure shows, a number of branchial arteries, but the consideration of these points is beyond our present purpose. We shall have a little more to say about them further on.

Leaving, then, the circulatory, let us pass to the *digestive organs.* The general simplicity of these parts would hardly justify us in directing especial attention to them, were it not for the presence in the gut of a most remarkable and curious apparatus, by means of which the food is slowed in its passage, and the nutriment to be gained from it thereby increased. This curious apparatus has had applied to it the very appropriate name of the *spiral valve* (Fig. 6).

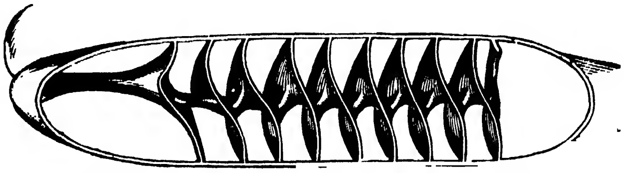

Fig. 6.—Spiral Valve of Dog-fish. (*After T. J. Parker.*)

In the earthworm* we find a ridge projecting from the upper wall of the intestine, but it is quite straight; in the lamprey this ridge has a wide spiral course; in the dog-fish and its allies the spire is much more close. One of these valves is shown in the adjoining figure (Fig. 6). The object of this arrangement is clear enough; it prevents the too rapid passage of the food through the intestine, and thereby enables the nutriment contained in it to be more completely absorbed. This structure is, so far as we know, always found in the fishes which belong to the same order as the dog-fish; but it is rarely found in the bony fishes. Among the group to which the sturgeons belong, and which in several points indicates that they stand mid-way between the sharks and rays on the one hand, and the salmons and the other *teleostei* on the other, we find it to be rudimentary in the gar-pike (*Lepidosteus*)—a form of which we shall have a good deal more to say hereafter. Only here does it remain to note that special appendages are connected with the stomach of the salmon and of its allies, which may well be regarded as replacing in function this elaborate and curious method by which the dog-fish makes the best of its chances in the way of nutrition.

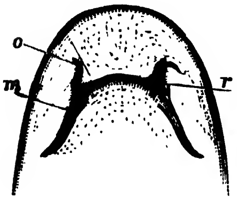

Fig. 7.—Nasal Groove of Scyllium. (*After Gegenbaur*).
m, Mouth; o, Entrance to Nasal Pit; r, Nasal Groove

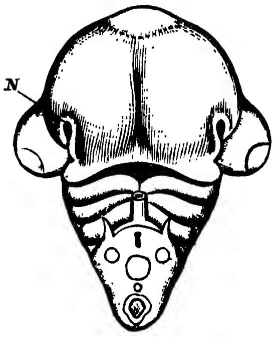

Fig. 8.—Chick's Head. (*After Balfour and Foster.*)
N, Points to the Nasal Pit.

Difficulties stand in the way of our dealing in detail with the brain and the other organs; of one curious point we must, nevertheless, say a few words. In all higher animals the nasal organs have two orifices within the mouth, but this is not the case with the dog-fish; in it the olfactory pit of either side is blind posteriorly, so far as an opening into the mouth is concerned, but there is a groove running from the pit to the angle of the mouth (Fig. 7), and this pit is covered over by a fold of skin; in other words, the *nasal groove* is superficial. In the dog-fish this is a permanent arrangement, while in the chick (Fig. 8) it lasts for a short time only.†

These, then, being the general characteristics of a dog-fish, let us sum them up in a more generalised way, so as to make the very best of the knowledge we have gained. The dog-fish is a vertebrated animal, with a brain-case, or cranium, with an internal brain, with a central heart of two cavities; with gills, which are only external for a brief period, but which never have their slits covered over by any fold of skin or any development of harder protecting matter; in which the original cartilage of the skeleton is never replaced by true bone; the cavities of the heart are systemic.

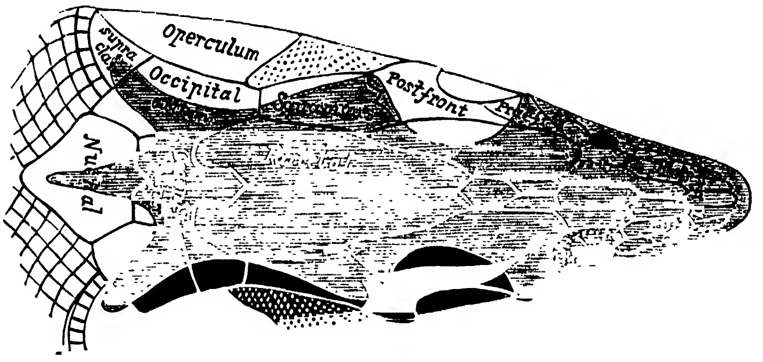

Fig. 9.—Skull of Sturgeon. (*After Gegenbaur.*)

These may be taken as the general characters of the dog-fish. Before we compare it with its own immediate allies, the sharks and the rays, let us compare it in its more general structural arrangements with a sturgeon. Here, the greater strength of the outer covering of scales at once arrests the attention, and that the more when we know that these scales resemble true bone in structure; more than that, some of the scales on the skull become very definitely arranged (Fig. 9), and foreshadow, in the most remarkable manner, some of the cranial bones of the higher vertebrata. This is, indeed, a very remarkable phenomenon; we have hard parts never pre-formed in cartilage entering into a defence of the brain, just as in the developing child or chick we have tracts of membrane becoming osseous plates, and completely fusing with the parts pre-formed in cartilage to form that complexly arranged box which forms the adult skull of the man or of the bird. Herein, just as in some other points, to be immediately noted, we see the great importance of the knowledge of some sturgeon-like fish for the correct understanding of the characters of the higher forms. Leaving the skull, let us turn to the girdle which forms the base of attachment for the fore-limbs (fins). In ourselves it is easy enough to distinguish two parts of this, the one the shoulder-blade (*scapula*), the other the collar-bone (*clavicle*). Now, in the dog-fish there is no representative of the latter bone, but there is such in the sturgeon; that it should not be seen in the dog-fish follows, if the statement be true that in it there are no parts of the skeleton which are not of cartilaginous origin, from the fact that the clavicular bones have no cartilaginous predecessors. That it might be present in the sturgeon is an easy enough matter to comprehend, the moment we grasp the fact that ossified parts from without (from the skin) extend inwards here, just as well as in the region of the skull, to take their part in the formation of an internal skeleton.

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* "Science for All," Vol. IV., p. 41.

† "Science for All," Vol. II., p. 197.

Before leaving this part we find that there is still another lesson which we can learn. If we are right, when tracing the pedigree of vertebrate animals, to regard those forms as the older which present the more simple arrangements of their parts, it will follow that the shark is an older form than the sturgeon; next, if the history of the development of an individual presents us with anything like an account of that order in which "fresh parts were developed in its ancestors," we should naturally expect to find that order followed in development which most naturalists believe to have been followed in the past. But this is not always so, and it is not hard to find the reason; the development of the individual is a "compressed history," and parts may still be sluggish in coming forward, while others seem to come more and more to the front. The shell of the mussel must have been acquired late in its time-history; but it is an important and characteristic structure, and in the development of some individuals, at any rate, it appears very much before the time at which we might expect it. Just the very same thing happens with the clavicle in man, for it is well known to be the first of all the bones of the body to begin to ossify. This is one example of the many which could be adduced which show that the course of tracing out life-histories requires very patient study, while, even by itself, it is an eloquent protest against the neglect of the comparative method—one of the most fertile and perhaps the most judicious and least dangerous of all the implements of our studies.

When we look for the gill-clefts of the sturgeon we do not find that they are patent, as in the dog-fish, but that they are covered over by a bony plate (*operculum*); this is a character by which the sturgeon and its allies resemble the bony fishes, and is, so far, a point by which they indicate their divergence from the general line leading up to the frog; some of them seem, however, to be provided in their very early stages with external gills, which are organs that the bony fishes never seem to have. Why we judge this to be a *piscine* character, and why we judge that to which we now turn as having a general vertebrate bearing, is again an example of the value of comparison. Till we come to the liver in the dog-fish we do not find any process given off from any part of the intestinal tract, but this is not the case with the sturgeon; from its gullet (or rather stomach) there is given off on the upper surface a duct which passes into a larger air-bladder which lies underneath the spinal column. Indications of this duct are seen in some of the sharks, but their very rudimentary outgrowth never becomes an air-bladder. In the bony fishes, on the other hand, a few only—such as the salmon, for example, have an air-duct; most have only the bladder, without any duct at all; the bladder is a mere closed sac; while others, again, have lost even the bladder, though their most immediate allies still retain it.

Interesting, then, as this organ is from the fact that even within the group of fishes we may see it appear in rudiment, become well developed, and yet still within the limits of that class disappear again, we are very far from having got to an end of its history. Leaving aside the great variations which it may exhibit in its form among the bony fishes, let us trace it further in its changes in the sturgeon's allies; but before we do that we shall, just to render matters a little simpler in explanation, look at ourselves. As all know, there opens into the top of the gullet, in man and all mammals, in birds and in all reptiles, a tube of varying length, situated ventrally to the gullet, which communicates with the two large air-sacs which we know familiarly as the lungs.

Now to trace the steps of the change. If we could watch, as the more fortunate American observers can do, the bony-pike (*Lepidosteus*), a close ally of the sturgeon, we should probably see just what Professor Burt Wilder saw:—"While watching the living gar, whether old or young, one of the first things noted is that it not only remains usually near the surface, but, at short intervals, actually protrudes the head from the water. In so doing, it turns partly over upon one side, emits a large bubble of air, executes a slight gulping movement of the jaws and throat, and sinks again below the surface; immediately afterwards a few smaller bubbles escape from the gill-slit on each side of the neck." Led by this, the writer of the above examined another form—*Amia*—in which he quite distinctly saw what he took to be a *gulping in of air.* This kind of thing is, of course, common enough with tadpoles at a certain age, which, as we know, gradually lose their gills and become provided with true lungs. When we examine the air-bladder of a *Lepidosteus* or an *Amia*, and compare it with what we find in the sturgeon, do we note any advance towards a lung in the structure of this part? The sac of the sturgeon is simple and its walls are not especially well provided with blood; a lung is always more or less broken up into smaller sacs, and its walls are very rich in blood. So it is with the two American sturgeon-like forms, and so it is with some of their allies. Two difficulties only remain; the lungs are double and are on the ventral surface; the sac of *Amia* is single, and is placed dorsally to the intestinal tract. Can a knowledge of any other forms fill up these two spaces in the sequence? Surely so; for the sac of *Lepidosteus* (the gar-pike) though single externally, is internally divided into two longitudinal halves; the Australian *Ceratodus*, with a single dorsal sac, has the duct to the left of the ventral surface; the African form, *Polypterus*, has the sac double, and the duct opening into the middle line of the ventral surface of the gullet. Here, then, our difficulties seem to have vanished, but they have not quite; one important point remains to be noted. In describing the heart of the dog-fish we stated that it consisted of but two cavities, that the blood from the ventricle went to the gills, and thence to the body, no special vessel returning blood from the organs of respiration directly to the heart, any more than in the gill-bearing tadpole; but, just as in this last, *pulmonary* vessels become connected with the lung, as development proceeds, so is it necessary for us to complete our links in the chain of evidence by finding some animal in which, while gills are present, special vessels supply the air-sac and return the aërated blood at once to the heart; this is not the case in *Polypterus.* Fortunately for our demonstration, an animal is at hand in the curious mud-fish of West Africa (*Protopterus*) and in the allied East American (South America) form *Lepidosiren.* In these remarkable fishes, the interest in which will yet for long continue, one of the vessels which goes to the gills gives off a branch which goes direct to the air-sac, and from the sac pulmonary vessels return direct to a portion of the here almost double auricle, which is set apart for the reception of their contents.

The reader will now be able to understand the general meaning of that difficult word *homology;* we will leave him to work it out for himself, and only say that while *homology* is applied to parts which have the same structure and history, the word *analogy* is applied to parts which have the same functions; thus the air-bladder of the sturgeon and the lung of a man are homologous organs, while the wing of a bee and the wing of a bat are analogous parts.

Other details in structure must be passed over; enough has perhaps been already put into the limits of a single essay, but what has been said will very largely have been said in vain if it shall not have shown how unity underlies diversity, and how these indications of the affinities of one animal to another are of the deepest and most abiding interest. We may well apply to them the words of an eloquent writer and distinguished embryologist, and say that they are "for the sake of those who can study and learn about nature."

It now becomes our duty to generalise a little what we have learnt. The dog-fish and the sturgeon have been taken as the types of two great divisions of the *Palæichthyes*—the Elasmobranchii (or pouch-gills), and the Ganoidei (or fishes with shining scales). Of these, the former is still richly represented in our seas; the latter is abundant in the earlier deposits of the earth, but, if we may speculate, has, in its tendency to become more fish-like, become gradually replaced by the characteristic bony fishes. Like many races of dying-out animals, it is now mainly confined to fresh water, and is found principally in the rivers of Russia, Africa (Nile), and North America. The forms of the Ganoids that now remain alive differ very considerably from one another; without including with them the Ceratodus of Australian rivers, or the mud-fish of which we have already spoken, we find that the seven genera now recognised as existing belong to four different sub-orders, each characterised by very well-marked differences. These we need not insist on, otherwise we could easily show that within the limits of this order the differences exhibited by different members are far from being slight. Did we add in the characters of the three sub-orders now extinct, we should have to deal with an eminently diversified series of forms. Thus is it true that, given certain characters, animals may and do vary most widely one from the other.

Turning to the Elasmobranchs, we find two very sharply-marked sub-orders; one contains the *Chimæra*—perhaps the most hideous of all fish—and that sub-order has the technical name of *Holocephali.* It is distinguished by a very important characteristic—the fact, viz., that there is no hinder bar of bone—hyoid-arch—connecting the skull with the jaws, in the way we have already observed in the dog-fish. Here the jaws and the skull are directly connected. This is a very rare arrangement among fishes, but it is a very common one, and indeed the only one, in all forms of higher vertebrata. The possession of this arrangement, then, in *Chimæra* must always be carefully borne in mind when we try to fix its relations to other forms, and the retention of this arrangement here shows us that we must always insist on carefully comparing every form on which we can lay our hands; for, so surely as we do so, so surely shall we again and again be rewarded by finding in some unexpected place a character which, lost or obscured for a time, re-appears in an emphatic way in some very distant members of the race. The other sub-order has the technical name of the *Plagiostomi*, and is that which contains the sharks and the rays. These may be at once distinguished from one another by the position of the gill-clefts, which are placed at the sides in the former (as in the dog-fish), and on the ventral surface in the latter. Among these last we find the saw-fish (*Pristis*), with its long projecting snout, armed on either side with a row of strong "processes." These are ordinarily known as teeth, but teeth they are not, inasmuch as they are not within the mouth; but teeth they may be called, if only we remember the fact upon which we have already insisted in detail, that the teeth are, after all, nothing more than external spines specially modified to serve a particular purpose in the economy of digestion. Thus are we brought almost to what we said at the beginning; but, more than that, we are brought back to the reflection that careful comparison of the wondrous unity of plan shows, even in external unlikeness, close resemblance in all essential points.

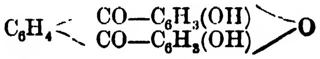
FLUORESCENCE.

By William Ackroyd, F.I.C., etc.

THERE are some appearances in nature which require particular looking for before one can find them, while others are so apparent that everybody may see them without the least trouble of any sort. To the latter class belong the phenomena of phosphorescence, which were dealt with in a former paper; for no one with eyesight ever experienced any difficulty in seeing the spark of the glow-worm, the mild light of decaying wood, or the faint luminosity of certain sulphides.* There is a class of appearances, however, very nearly related, if not identical with phosphorescence, which may escape one's attention if they are not pointed out. It is related of Faraday that upon one occasion a scientific friend was about to show him an experiment, when the great philosopher requested in the first place to be told what he had to look for; and in the study of *fluorescence* one must decidedly know what to look for, or else run the risk of not seeing it. The reader has doubtless seen paraffin-oil many a time, and has perhaps filled his lamp with it, yet it is very probable that he never saw anything peculiar in it, but if the phenomenon had been pointed out to him he would have seen its fluorescence.

We can perhaps best learn what this fluorescence is like by comparing a couple of solutions, one fluorescent and the other not. A solution of the aniline dye magenta is not fluorescent; therefore dissolve a few grains of it in water, and examine the coloured solution in every available position with regard to the light. It will then be found that it appears of the same tint always, no matter whatever direction the light enters into it. This is not, however, the case with a fluorescent solution.

There is a substance called "fluorescein," which may next be dissolved and compared with the magenta solution. It is a red crystalline powder, almost insoluble in water, but readily dissolving in water containing ammonia. Like ordinary wood, it consists of the three elements carbon, hydrogen, and oxygen, its composition being represented by the chemical formula—



$$C_6H_4 < \begin{matrix} CO—C_6H_3(OH) \\ CO—C_6H_3(OH) \end{matrix} > O$$

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* "Science for All," Vol. IV., pp. 47-53.

Its solution is fluorescent; therefore add a few drops of ammonia to a glassful of water, and then drop into it as much fluorescein as will cover the tip of a pen-knife blade (Fig. 1). The beauty of the phenomenon which then presents itself is quite surprising. A little brown patch is seen on the surface of the water where the powder has dropped, and from this a great many brilliant green stems shoot down into the water. If all the fluorescein in the descending shafts be not dissolved before the bottom of the tumbler is reached, there appears at the end of each of them a yellowish-brown ring. The phenomenon is not unlike the sudden birth of a number of marvellously beautiful aquatic plants, or of a fairy-like Medusa sending down its tentacles like green snakes, and for this alone the experiment is well worth trying. It is, however, only a view by the way, noted just as the passing traveller would note the beauties of wood and dale on his journey to a certain town; and all this beauty within the tumbler must now be ruthlessly destroyed by stirring up the solution.

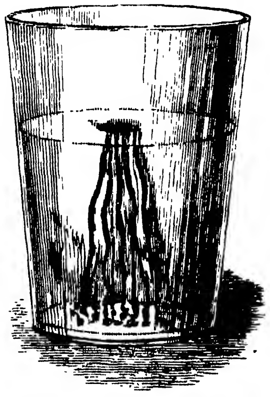

Fig. 1.—An Experiment in Fluorescence.

The solution now seems uniformly coloured throughout of that lovely green which was observed in the descending filaments, but if the glass be held up before the window (*a*, Fig. 2), so that light may pass straight through it on its way to the eye, then, instead of the green colour, one observes a sort of pale orange, and this is what one might term the real colour of the fluorescein solution, just as pink is the real colour of a weak magenta solution. How comes it, then, that the fluorescein solution has not this faint orange tint in every position with regard to the light? The answer is, because the solution is a fluorescent one, and the bright green colour you observe is its fluorescence, a faint light which it is emitting while under the influence of the sun's rays.

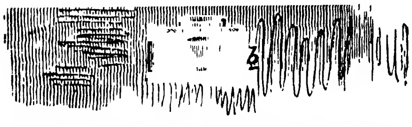

Fig. 2.—How to see Fluorescence, and how not to see it.

Bring the glass of fluorescein solution just under the bottom of the window, and place a black-backed book behind it, so that light cannot pass horizontally through it, but has to proceed downwards, as at *b*, Fig. 2. A curious phenomenon will now be observed, which is a distinct mark of fluorescence. The green light now, instead of being apparently diffused throughout the whole liquid, looks as if it were nearly, if not entirely, confined to a thin layer at the upper surface, so that the observer with his eye at *c*, Fig. 3, sees quite a green surface stratum of light at *a*. Now this is peculiar, because upon bringing the glass of magenta solution into the same position under the window bottom, and looking at it in precisely the same way, nothing extraordinary is noticed, the weak magenta solution appearing of the same pink in the middle as it does at the surface. And any other solution in the same position, and not fluorescent, would behave like the magenta solution, *i.e.*, have a uniform colour throughout.

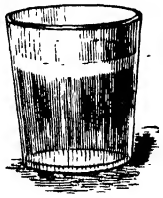

Fig. 3.—The so-called Surface Dispersion.

In the same way one may contrast paraffin oil and water. The latter, in whatever position you hold it, appears colourless, and the oil is nearly colourless, but in certain aspects it appears as if tinged with blue. Pour the oil into a clean tumbler, and examine it as in Fig. 2. In position *a*, with light coming through it to the eye, the oil appears decidedly yellowish; but in position *b*, without the black book at back, one sees a deep blue surface stratum. The paraffin-oil evidently mildly shines with a deep blue fluorescence.

It will be clearly seen now what one has to look for in observing fluorescence. We have as yet, however, said nothing about the inner nature of the phenomenon, how it is started, and how it is kept on. It is a question of the action of ether waves on the atoms of substances. The reader will have no difficulty in imagining that these ether waves * may move the atoms, and shake or make them vibrate, as the ripples of a pond shake the reeds on its banks; but he has further to imagine that just as it would be possible for these shaking reeds to originate new ripples, so is it possible for the vibrating atoms to originate new ether waves, or, in other words, to become sources of light. Thus, then, a modern physicist thinks this matter out:—A fluorescent substance, like most other substances, absorbs more or less of the radiations proceeding from the sun, whether they be visible to us, like light, or invisible, like the rays beyond each end of the spectrum. And wherever this takes place work of some sort is done. If the very short wave radiations which have their place beyond the violet portion of the spectrum be absorbed, we may have chemical action, as in the change wrought in compounds of silver, which is utilised for photographic purposes; the absorption of other rays may give rise to the movements of the radiometer vanes; or, what is more to the point, this absorption may give rise to the light emitted by such substances as Balmain's luminous paint. In this phosphorescent substance light is first absorbed; the motion of certain ether waves is stopped by being imparted to the minute, yet comparatively ponderous, atoms of the phosphorescent powder, and the swinging atoms become a fresh source of agitation to the ether, the powder thus becoming an independent source of light. Even so is it in fluorescence. Rays are first absorbed, and the atoms of the substance which are made to shake become a source of other rays quite different. Stokes gives the following illustration of what he supposes to take place in this phenomenon of fluorescence:—"Suppose," he remarks, "you had a number of ships at rest on an ocean perfectly calm. Supposing now a series of waves, without any wind, were propagated from a storm at a distance along the ocean: they would agitate the ships, which would move backwards and forwards; but the time of swing of the ship would depend on its natural oscillation, and would not necessarily synchronise with the periodic time of the waves which agitated the ship in the first instance. The ship, being thus thrown into a state of agitation, would itself become a centre of agitation, and would produce waves, which would be propagated from it in all directions. This I conceive to be a rough dynamical illustration of what takes place in this actual phenomenon, namely, that the incidence of etherial waves causes a certain agitation in the ultimate molecules (or atoms) of the body, and causes them to be in their turn centres of agitation to the ether." In short, the atoms of a fluorescent substance send out fresh waves of their own when agitated by the waves of the ocean of ether which surrounds them, these waves proceeding from some distant storm centre (a flame) where

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* "Science for All," Vol. I., p. 190.

> " . . . . The flaring atom-streams
> And torrents of her myriad universe,
> Ruining along the illimitable inane,
> Fly on to clash together again, and make
> Another and another state of things
> For ever."

Now this is a very efficient theory, for it will explain all we know of fluorescence, and we may as well now see how the various facts adapt themselves to it. The medicine quinine, when dissolved in water to which a little oil of vitriol has been added, shows a beautiful blue fluorescence. If now we project on to a screen the spectrum of the sun by means of a quartz prism, we shall obtain a rainbow ribbon of colour extending from red to violet, and beyond the red there will be projected rays of longer wave length, quite invisible, and remarkable for their warming power, while beyond the violet there will be projected rays also invisible and of very short wave length, remarkable for their photographic action (Fig. 4). In this latter dark portion of the spectrum place the solution of quinine: it immediately shines with its blue fluorescent light. Now, according to theory the ultra-violet rays have been partly absorbed, the quinine atoms set vibrating, and rays of different wave length have been originated. This thoroughly accords with experiment, for the latter fact is evident to the senses alone, inasmuch as invisible ultra-violet rays have, after entering the quinine, given rise to visible rays of light; and you will find that after a sunbeam has passed through such a solution of quinine it is no longer able to produce fluorescence in a second solution of the same

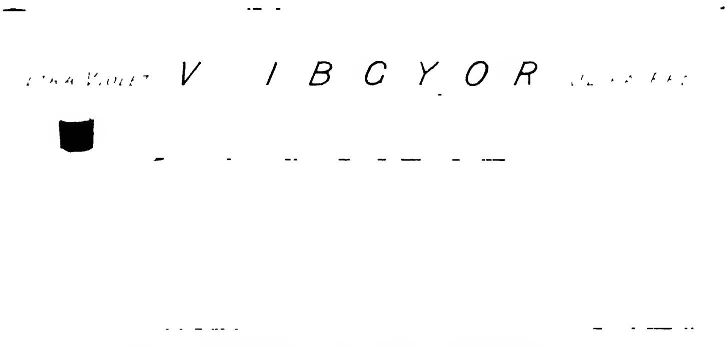

Fig. 4.—Fluorescence produced by Invisible Rays.

substance, for the rays which produce the effect have been absorbed by the first solution. This enables us to explain the surface light of fluorescent solutions which is seen under such circumstances as we have described. When the light comes through the window down into the fluorescent solution, the rays which produce fluorescence are absorbed before they have proceeded far into the liquid; hence, deep down next to no fluorescence is produced, while at the surface a stratum of liquid, varying in thickness with the strength of the solution, shines very markedly with the fluorescent light.

When the phenomenon of fluorescence began first to attract attention, it was supposed that it was somehow due to dispersion of the light falling on the substance, and it was named by Sir John Herschel *epipolic* or *surface* dispersion, while Sir David Brewster called it *internal* dispersion. The idea underlying these hypotheses of dispersion seems to have been this: that particles were suspended in the fluorescent media of such a size that they could reflect certain light rays, and thus give rise to what we now term fluorescence. It has long been known, however, that when light is reflected from particles in this way it becomes polarised,[*] that is, it suffers such a change that if you examine it with a Nicol's prism which is kept rotating on its axis there ought to be alternate brightening and darkening of it—as great a difference, in fact, as that presented by a still sheet of water in sunshine and the same expanse when overhung by sombre clouds. But in some of the examples of fluorescence that were examined there was not this alternate brightening and darkening: in other words, the light was not due to reflection such as they supposed. This absence of polarisation in fluorescent light again accords with Stokes's theory, for being generated quite newly, like the light of a candle, one would not expect it to be polarised. It will thus be seen that the theory is perfect so far as our present knowledge goes, for it serves to explain all the facts we know about fluorescence; but it will be apparent, from the remarks made when discussing phosphorescence,[†] that these two phenomena of fluorescence and phosphorescence are both alike so far as the exciting cause is concerned, and the question will have arisen, In what do they differ? Probably the main point of difference is that which distinguishes an hour from a year or a second from a day: in other words, a difference of duration; for while in the case of phosphorescence the effect may last for hours, as in the sulphide of barium, the time fluorescence lasts is too short to be ascertained.

There are very many substances which exhibit fluorescence, and we may conclude this paper with just mentioning one or two. The mineral fluor spar is remarkable for its fluorescence, the purplish variety emitting a deep blue light when under the influence of the sun's rays. It was the study of the appearance presented by this mineral which led to the naming of the phenomenon, the word fluorescence being derived from *fluor* spar, and referring to the blue light of the spar, just as opalescence is derived from opal, and refers to its milky appearance. The retina furnishes another remarkable case of fluorescence. It has been made out by Helmholtz and others that when a retina is examined in the ultra-violet light it has a bluish fluorescence, and according to Kühne and Ewald it alters its fluorescence to green after being bleached. The bark of the horse-chestnut contains two fluorescent substances, fraxin and esculin, so that if you float a piece of the bark in a glass of water to which a few drops of ammonia have been added, descending streams of the fluorescent light soon make their appearance. The dyewares fustic, camwood, and turmeric also furnish fluorescent solutions by proper treatment, the first in a solution of alum and the second and third in castor-oil.

THE SILKWORM DISEASE.

By Albert Brydges Farn.

ONE hears now-a-days, and on all sides, that "silks" are not so good as they used to be, that they do not "wear so long," and that there is a lack of substance in them. Silks that would "stand alone" seem to be things of the past. This deterioration being important, both from an economical and a scientific point of view, some inquiry into its principal cause may be interesting. The main cause of this loss of virtue in "silks" is, doubtless, the disease among the silkworms. Not only has this disease weakened the silk-producing powers of the "worms" themselves, but by slow degrees it seems to have exterminated those species which produced the finest quality of silk: the species, in fact, which formerly were constantly reared in Europe, and which produced the material for those fabrics the disappearance of which is so much regretted by the ladies. It has been generally thought by those who have not studied the natural history of silkworms that silk, such as is usually worn, is the production of but one species; but in reality several closely-allied species have, from time immemorial, been pressed into the service. Fig. 1 gives a fair general idea of the moth of the silk-producing species now under discussion. The notion above alluded to would be quickly dispelled if comparison were made between the cocoon spun by the species which used to be reared in Italy with the cocoon the product of the species now generally reared, and which is imported from Japan, though this latter must not be confounded with the "Japanese silkworm," which is an entirely different species. The cocoon from which used to be wound the strong rich Italian silk, so highly prized, was long, the circumference largest in the middle, becoming shuttle-shaped as unreeled, and of a fine lustrous amber or white; while that which has to do duty at the present day is much smaller, of a double-lobed appearance (the circumference not largest at the middle), not so lustrous in appearance, and of a pale greenish straw colour. The former yielded not only a much greater quantity of silk. but the quality of the silk was much stronger, so that a fewer number of cocoons, when wound together, were required to make a silken thread. The accompanying illustrations (Figs. 2 and 3) show the difference of shape.

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[*] "Science for All," Vol. I., p. 197, and Vol. II., p. 355.

[†] "Science for All," Vol. IV., p. 53.

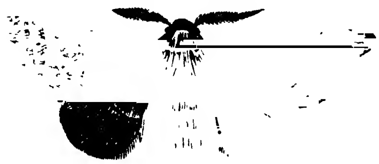
Fig. 1.—*Bombyx mori* (Male).

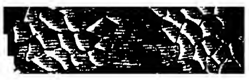
Fig. 2.—Cocoon contracted towards Middle

The nature of the disease which has caused the extermination of the best silk-producing worms, and which threatens the total extinction of the silk industries—unless, indeed, either prompt measures be taken to combat the disease itself, or fresh species of silk-producing worms are brought within reasonable control and cultivation—may be best understood by giving a brief account of its origin and progress.

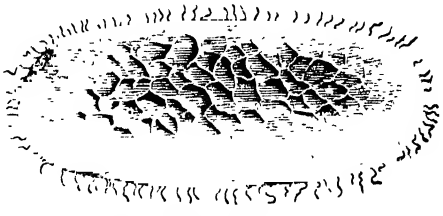
Fig. 3.—Oval Cocoon of *B. mori*.

M. Pasteur was commissioned by the French Government to inquire into the nature of the disease, and unlimited resources were placed at his disposal, so that the results of his study should be worthy at once of the nation and of the man. To this exhaustive report the writer is largely indebted, not only for the principal facts in this paper, but for guidance in carrying out many experiments in confirmation of the theory there expounded. In France, in 1849, after an unusually abundant crop of silk in the previous year, it was observed that in many districts, without appreciable cause, whole broods of silkworms had perished. The following year there were even greater losses, and in fresh localities, and still no definite reason could be given for these disasters. The evil increased during the three or four following years, but, in spite of it, silkworm rearing was so profitable that an increased number of rearers each year engaged in the business, so that the net result in cocoons grew steadily larger and larger. In 1853 there was a greater weight of cocoons raised in France than had ever been produced, and the yield of that year has never been equalled. The success of 1849 had stimulated an industry which had not till then attained large proportions, viz., that of raising silkworms, not for the silk they will produce, but for the eggs, technically called "seed," which are deposited by the female moths (Fig. 4). Strange as it may seem, it is nevertheless true, that an increased quantity of "seed" did not produce a relatively increased quantity of silk. One industry strangled the other. In days now long past, the silkworm rearer reserved certain of the finest cocoons which had been spun by his worms, so as to breed from the moths which would emerge. It is evident that the healthier the silkworm, the finer and heavier the cocoon it will produce, so the finest cocoons were devoted each year to the perpetuation of the breed during the next season. From healthy silkworms we may expect healthy moths, and from healthy moths healthy seed. And so in times prior to the origin of the "seed trade," each silkworm rearer knew the antecedents of the objects of his culture, because he had himself reared the parent moths. Among silkworms, as among human beings, there is always disease of an uncertain amount, and the "rearer for silk" (as opposed to the "rearer for grain") knew that unless his worms were kept as much as possible under healthy conditions, small would be the amount of silk they would produce for his benefit; because if he allowed unhealthy conditions to continue, disease, which might till then be latent, would soon manifest itself in a disastrous fashion. Most of us have a great opinion of the unknown, and doubtless this feeling induced certain rearers to try seed produced from silk moths of a foreign origin. Now, whether the home-produced silkworms had from too close inter-breeding to some extent deteriorated, it seems pretty certain that the trial of seed from a fresh source resulted in very favourable crops. This, of course, increased the desire for fresh seed, and thus augmented the demands made upon those who reared for seed only. And from this time we may trace an ever-increasing mortality among the silkworms, a mortality, as we shall presently see, intimately connected with the trade of the egg-rearer. Year after year the praises of foreign seed were sung by the fortunate silk raisers, but there was this curious circumstance attached: that the foreign seed the success of which was thus vaunted, was always from some newly opened-up district. One such district after another appeared, meteor-like, as a real Eldorado for a year or two, then sunk to rise no more, and to be remembered not so much for the success which had at first attended the importation of its seed, as for the dire misfortune it had subsequently brought on the silk industry. The following facts bear out this assertion.

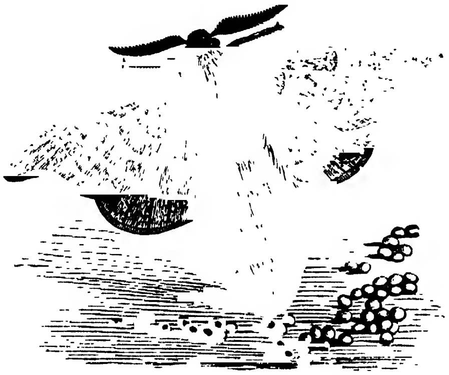
Fig 4.—*Bombyx mori* (Female) depositing Eggs or "Seed."

In 1853 seed imported into France from Italy produced an abundant crop of silk, but the disease invaded Lombardy, and in 1854 there were many failures in France from Italian seed; these losses were more numerous in 1855, and in the following year there was an almost total failure. Spain having experienced a similar misfortune, it became necessary for the seed merchants to go farther afield. During these first years of success the unhappy silk rearers had become infatuated with these foreign eggs, and had neglected to reserve any cocoons of their own rearing for seed, as they had formerly been accustomed to do. For not only did this foreign seed promise remarkable success, but the silk-rearer could utilise the silk of every cocoon his worms produced, as he no longer lost the silk of cocoons which were formerly kept to produce moths. They thus found, when too late, that they had left for themselves no retreat; they were altogether dependent upon the importation of foreign eggs for their silk crop. When, as we have seen, the seed merchants had to seek "fresh woods and pastures new," they went to the isles of the Archipelago, to Greece, and to Turkey. As usual, new districts yielded seed of remarkable purity, and once more the hopes of the silk rearers were raised, but only to be again disappointed, for in 1859 and 1860 the disease decimated the silkworms destined for seed in Turkey. Once more, the seed merchants went farther away into the Levant. Syria, the Caucasian provinces, Wallachia, and Moldavia were consecutively drawn upon for seed, and in turn abandoned as they became invaded by the disease. In 1864 all the seed-producing countries of Europe and part of those of Asia produced nothing but infected seed. The extreme East and Japan alone remained. We have seen how this disease dogged the footsteps of the seed merchant; and it will be observed that the interests of the silk rearer and those of the seed rearer, although at first sight apparently almost identical, are in reality widely different. We all know that certain diseases of human beings may for a long period pass almost unheeded, until some outburst of unusual virulence and magnitude creates alarm. Furthermore, we know that such an outburst is almost sure to be traced to certain unhealthy conditions which have been allowed to accumulate. Isolated cases of disease may occur and seem to defy our greatest vigilance, but it is in places where unsanitary arrangements—overcrowding, insufficient drainage, and impure water—are permitted that disease is rife. And similar conditions—overcrowding, insufficient ventilation, and the like—produce similar results among silkworms. While the silk and the seed rearing were under the same person's control, sanitary conditions were studied, because neglect on this head brought swift punishment in its train; but when they became separate industries, the utmost care of the silk rearer could but partially counterbalance the neglect on the part of the seed rearer.

But why, it may be asked, should there be neglect on the part of the seed rearer? The answer is this: the "trade in seed" was a most lucrative one, and the sole object of the seed merchant was to be able to sell as much seed as possible. To do this he would raise in a rearing-house three or four times as many silkworms as the space would permit—due regard being had to prevent overcrowding. It was this overcrowding that intensified the disease, and when, as will be shown, the disease is at once contagious and hereditary, it may readily be conceived what dire consequences would accrue when silkworms were thus crowded together. Again, the seed merchant had learnt from experience that the length of his stay in any one district would not exceed three years, so that he would not go to the expense of building properly-constructed rearing-houses. Besides, they bought up, right and left, all the cocoons which they could, and the natives of the district soon found that they obtained a better price for their cocoons by selling them to the seed merchant than they would for the silk if they went to the trouble and expense of reeling it. Thus the greed of the seed merchant was communicated to the natives, and they vied, one with the other, who should produce the largest number of cocoons, not for their silk, but for the moths which would emerge, and which would produce the seed for the merchant. It is manifest that the temptation was great to the seed merchant to rear two or three times the number of worms that his space would properly admit of, because they would produce a corresponding increment of seed; and if that seed should in the silk rearer's hands turn out badly, the seed merchant, having been already paid for his seed, could view with equanimity a failure which did not touch his pocket. It will thus at once be seen that the separation into two industries—silk rearing and seed rearing—of that which had been formerly considered but one, must be looked upon as a prime factor in the disasters which we have described.

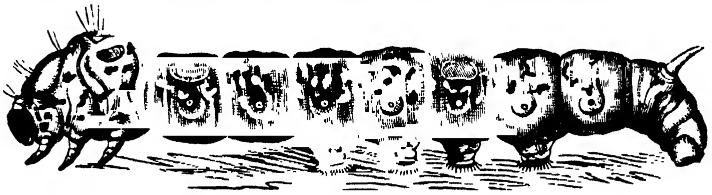

Fig. 5.—Silkworm affected with "Pebrine."

Rightly to gauge the magnitude of this evil of overcrowding, the discoveries of M. Pasteur in his inquiries into the nature of this disease must be explained. The diseased worms exhibit on their skins small black spots, as though they had been peppered; hence the technical name of "pebrine," or "pepper-disease," as it is called in the south of France (Fig. 5). These spots, when magnified, are found to be surrounded by a yellow tint. The spots are symptoms of a constitutional disturbance in the worm, just as we see blotches on people who are suffering from some internal derangement. If the tissues of a worm having these spots be examined under a microscope, small, shining, oval, bodies —corpuscles—may be observed. These are parasitic bodies which, producing internal derangement of the worms, are the cause of the spots on the skin, and the death of the worm. If we smear some of these corpuscles on the food of a healthy worm we convey to it the disease. Many of these parasites pass with the dejecta (known to entomologists as "frass") out of diseased worms, and, falling on the leaves on which perchance healthy worms are also feeding, infect them. This demonstrates the infectiousness of the disease, though it is but one way in which the plague may be communicated. Worms, either healthy or diseased, crawl over this frass, and smear their front legs (pro-legs), to which certain of these corpuscles adhere. The worms then crawl the one over the other, and it often happens that the pro-legs, which have sharp terminations, puncture the skin of worms which are healthy, leaving in the wounds thus inflicted one or more of the adherent corpuscles. A healthy worm undergoing this operation becomes inoculated with the disease, just as small-pox was inoculated in days gone by, or as is vaccinia, or cow-pox, at the present time. We may test this statement by inserting with a fine needle some of the corpuscles under the skin of a healthy worm. The disease may be communicated in yet another way. The frass, when it and the corpuscles have become dried, forms an impalpable dust, which may be blown direct on to food destined for healthy worms, or it may fall on the clothes of an attendant on healthy worms, who will thus quite unwittingly convey the disease to his charges.

In this way disease was, on one occasion at least, conveyed to hitherto healthy worms, which had been carefully fed and most rigorously supervised, until one day a person who had been rearing infected worms by chance brought them food, and unknowingly brought with him the dust from an infected rearing-house. If, as has been proved, the infected dust of one *magnanerie* (rearing-house) may be conveyed to, and produce the disease in, the worms of another *magnanerie*, it may readily be conceived, by a glance at the accompanying illustration (Fig. 6) of the interior of a rearing-house, that it is almost an impossibility that any silkworms can long continue healthy, if "*pebrine*" has once shown itself in the house. Certain worms may escape infection from leaves defiled by "frass" of infected worms, or even from inoculation by punctures from the frass-besmeared prolegs of its neighbours, but that they should escape the disease borne to them by every breath of air, in the form of the almost impalpable dust of the rearing-house, seems incredible. Particularly when it must be remembered that every facility is given to the dissemination of the dust throughout the rearing-house by the necessity of the thorough ventilation required in the building. Any one current of air may scatter death among the worms. We see, therefore, how highly contagious is the disease. But beyond this, it is also hereditary. Supposing a healthy worm has become infected only when nearly full-grown. The disease progresses in its interior, but has not attained sufficient importance to prevent the worm spinning its cocoon and changing into a chrysalis, from which a moth will emerge. But it will be found that this moth, supposing it to be a female, will lay eggs which will contain parasites. The parasites pass into the eggs in the following way: when a silkworm first changes into a chrysalis the interior of the chrysalis is filled with a creamy-like fluid, and it is only after the lapse of some little time that this fluid begins to assume some of the proportions of the moth which will ultimately emerge. Little by little the wings, legs, and internal organs, &c., of the future moth begin to

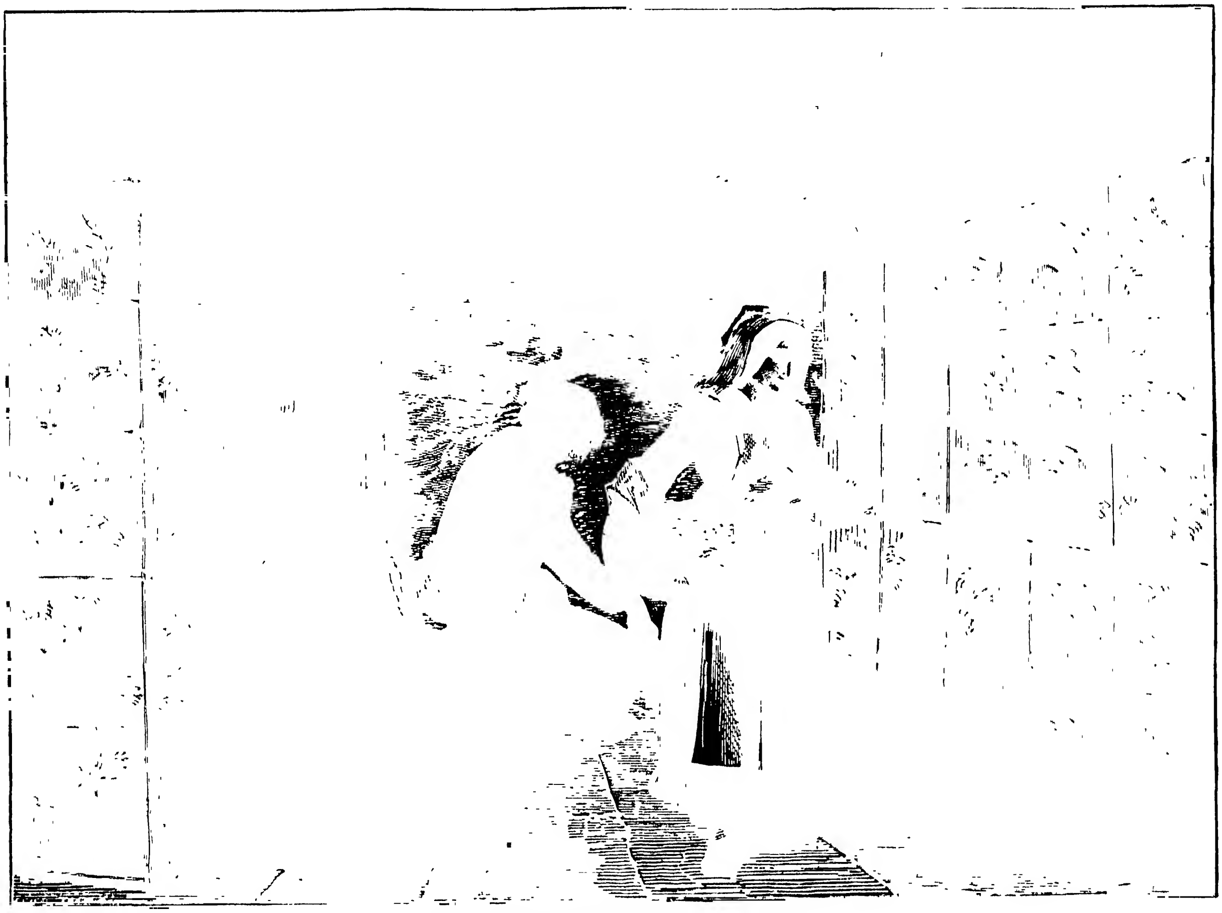

Fig. 6.—MAGNANERIE, OR REARING-HOUSE.

assume a definite shape and consistence, until, all being ready, the skin of the chrysalis bursts, and the perfect state of the insect is assumed. Before the formation of these various parts of the perfect insect takes place, the corpuscles can float uninterruptedly in the interior of the chrysalis, and so it happens that as the walls of the eggs (to be by-and-by laid by the moth) are forming, certain of the corpuscles are enclosed. When, therefore, the moth lays its eggs, these eggs are already infected, because they contain certain of the parasites.

If such eggs be crushed, mixed with a drop of water, and examined under a microscope, these parasites may be readily detected. Very many of these eggs will, from this cause, prove sterile, and those which hatch will produce worms carrying within them the seeds of this dire malady. These parasites increase rapidly, and it will be found that a large proportion of the worms born with the disease in them never live to attain their full size,- much less produce cocoons,—because of the large number of parasites which are inwardly preying upon the vital juices of the worms. Now, special parasites have special habitats. We may instance the *Pediculus capitis*—the horror of cleanly people—the *Trichina spiralis* in muscle, the chigoe in great-toes, the tapeworm (*Tænia solium*) in the intestines, &c.; and M. Pasteur asserts that the habitat peculiarly affected by this parasite of the silkworm is the silk glands of the worms (Fig. 7) in which is secreted the viscid gum-like fluid which, when ejected by the worm in a fine thread, forms silk. He states as evidence that, supposing a worm has contracted the disease at an early stage of its existence, but not so early as to prevent its attaining its full growth, it will, when the time comes for the spinning of its cocoon, seek some suitable position, and then commence to slowly pass its head from side to side, and go through the movements as though it were spinning a palpable cocoon, while in fact no silk passes from it, and in reality it is only an imaginary cocoon it is weaving. M. Pasteur states that if the silk-secreting glands of such a worm be dissected, they will be found not distended with the viscid fluid necessary to the formation of silk, but with myriads of the parasitic corpuscles, which have increased and multiplied to such a degree in the glands as utterly to preclude the secretion of the fluid silk.

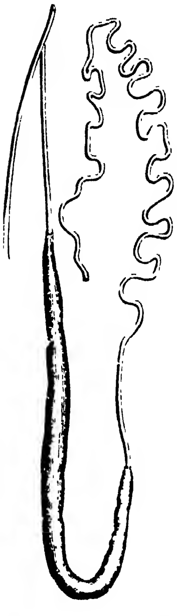

Fig 7.—Silk-secreting Apparatus.

This, then, is the disease *par excellence* of the silkworm, and although there are other causes of mortality more or less great, these may, comparatively speaking, be readily guarded against by a careful rearer. But when, as has been shown, "pebrine" may be introduced into the rearing-house in so many various ways, and makes its approach in such an insidious manner, no wonder that its ravages have been the cause of both surprise and dismay in the unhappy silk rearer. Remembering the rapidity with which it may spread in well-conducted rearing-houses, we may picture its dissemination in houses crammed by worms, whose owners have no direct interest in the silk the worms will produce, and we need seek no farther for an explanation as to why it was that one district after another succumbed to the greed of the seed merchants.

The extent of the damage caused by this disease may be best estimated by the following figures from the official returns of the annual production of cocoons in France alone, which are as follows:—

From 1821 to 1830, 10,000,000 kilogrammes* of cocoons.
,, 1831 ,, 1840, 14,000,000 ,, ,,
,, 1841 ,, 1845, 17,000,000 ,, ,,
,, 1846 ,, 1852, 21,000,000 ,, ,,
In 1853 26,000,000 ,, ,,

when the operations of the seed merchants attained their maximum, and a decline in silk-producing commenced.

	Kilogrammes of cocoons.
In 1854 there were produced ...	21,500,000
,, 1855 ,, ,, ...	19,800,000
,, 1856 ,, ,, ...	7,500,000

and progressively

	Kilogrammes of cocoons.
In 1863 the produce declined to...	6,500,000
,, 1864 ,, ,, ...	6,000,000
,, 1865 ,, ,, ...	4,000,000

Compare the foregoing figures, which relate to *France alone*, with the following, which are estimates of the yield of cocoons for the *whole of Europe*, as given in the *Moniteur des Soies*, an authoritative journal on all that relates to silk culture.

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* A kilogramme is 2·205 lbs. avoirdupois.

The Yield of Cocoons for the whole of Europe.

1874	3,700,000 kilogrammes
1875	3,500,000 „
1876	1,250,000 „
1877	2,400,000 „
1878	3,400,000 „
1879	1,190,000 „

The temporary increase in 1877–8 may probably be attributed to the opening up in Japan of fresh districts for seed, as in 1874 the Japanese Government first rescinded the laws against the operations of the seed merchants in the interior of the country. It must be borne in mind, as already stated, that the silk from the Japanese worm has neither the substance nor the lustre of the silk formerly produced by the Italian worms—a race, it is to be feared, quite exterminated. By the light of the foregoing figures may we not foresee the almost, if not utter, extinction of the silk industry, unless heroic measures are promptly taken to combat the evil?

A CHEMICAL LABORATORY.

By F. R. Eaton Lowe, M.A., Ph.D., etc.

Who has not been amused by the stories of the alchemists of old, and smiled over the narrative of their researches after the "philosopher's stone"? While we may affect to despise the ignorance of these deluded philosophers, it is impossible to repress a feeling of admiration for the indomitable perseverance with which, in spite of repeated failure, they continued their random experiments throughout a life-time devoted to one grand object—the transmutation of the baser metals into gold. The uniform want of success which attended their efforts only seemed to stimulate them to new devices and fresh experiments; and the non-appearance of the long-expected gold only strengthened their determination to succeed. These men, however, knew nothing of the most elementary principles of chemistry upon which their researches could be based; they worked literally and figuratively in the dark. As fire was the agent to whose potent help they looked chiefly for success, the furnace was regarded as the most mystical and therefore the most important part of their gloomy, cavernous laboratories; but the grim glare which occasionally issued from this served to do little more than make the "darkness" visible. As their experiments were based upon no rational theory, and, in fact, upon no theory at all, they were necessarily tentative and haphazard, and were, therefore, little less desultory than those of the embryo chemist of more modern times, who mixes together all the reagents in his guinea chest of chemicals, with a view of bringing about some great and unexpected result.

It is somewhat surprising that these indefatigable workers, who were not wanting in shrewdness, failed to see that the realisation of their hopes would simply result in an excessive depreciation in the value of gold, and the substitution of some other metal as a medium of currency. But the researches of the alchemists, unscientific as they were, led to results the importance of which was not duly appreciated till the fallacy of metallic transmutation had been exploded. The random experiments of these men conduced to the development of the noble science of chemistry, which has furnished so many of the elements of modern civilisation. A large number of disconnected facts and results were accumulated by the alchemists in the course of their researches; but it was not till the eighteenth century was near its close that these facts and results were systematised, and the fundamental principles of chemistry satisfactorily elucidated. The discoveries of Priestley and Scheele between the years 1770 and 1790 served completely to cancel the meagre list of elements as given by the alchemists. Earth, air, fire, and water were displaced from their pedestals as the sole constituents of the material world; and a number of new elements, the list of which was largely increased by Davy and his immediate successors, appeared to console the disappointed adherents of transmutation.

A number of chemical reagents which were discovered in the search for gold still retain their old names, such as aqua-regia, aqua-fortis, oil of vitriol, and spirit of salt; while the philosophical toy known as "Prince Rupert's drop" still remains as a souvenir of that "fiery Rupert of the Rhine," who sought consolation for his defeats at Marston Moor and Naseby by scientific recreation in his laboratory at Windsor Castle.

As soon as Priestley's discovery of oxygen threw light on the composition of acids and salts, the number of these compounds became vastly augmented, and a rapid and striking advance took place in the arts and manufactures. New discoveries of eminent advantage to mankind followed one another in rapid succession; and at the present moment the labours of the chemist at home and abroad are being rewarded by a rich harvest of products of vast interest, not only to the scientific, but to the commercial world. Let us, then, look into the chemist's workshop, and take a rapid survey of the curious pieces of apparatus standing upon the shelves, or suspended from the walls.

In the best laboratories there is a separate room devoted to *qualitative* analysis, and another to *quantitative* analysis. In the first the processes necessary for the determination of the constituents of any given substance are carried on, while in the second the absolute weight or volume of such constituents is ascertained by processes of a different kind. In some laboratories there is a third room for operations of a more cumbrous character, such as furnace work, glass-blowing, smelting, and the manufacture of gases in quantity. In laboratories especially constructed for teaching, there is a compartment provided with its own water-pipe, Bunsen's burner, and sink for each student; while the reagents and simpler pieces of apparatus required in ordinary analysis, such as retort stand, test tubes, funnel, and blow-pipe, are placed within easy reach. Order and cleanliness are two qualities of the first necessity in every laboratory. Every bottle must have its appointed place, to which it must be returned immediately after use; while all flasks and test-tubes must be thoroughly cleansed before being replaced, or the results of the next experiment may be sadly vitiated. The ventilation of a laboratory is a matter of considerable importance, as fumes of some kind or another will escape under the most careful management; but the manufacture of noxious gases should be carried on in an apartment altogether cut off from the principal testing rooms, and bottles containing volatile acids and ethers should be kept well closed with greased stoppers.

Amongst the most useful glass vessels used by the experimental chemist are *retorts* and *flasks*, of which a large stock is usually kept, as breakages are of every-day occurrence. Retorts are of two kinds--plain and tubulated; the former being without tubulature can therefore only be filled through the neck. A flask and bent tube can be employed instead of a retort, and in some cases are preferable.

Sometimes—as in the manufacture of chlorine gas—there is a good deal of frothing up, and unless this be allowed for by the use of a retort of sufficient capacity, the materials distended by the disengaged gas will be forced into the neck, and thence into the gas bottle. In making carbonic acid, where the heavy gas is collected simply by the displacement of common air, the delivery tube passes to the bottom of the gas-bottle, which is gradually filled. The insertion of a lighted taper will show, by its extinction, the presence of the gas. A large retort is useful in the preparation of distilled water—a supply of which must always be at hand in the laboratory, as no other water is admissible for analytical purposes. The distilled water sold by the druggist is usually distilled in copper retorts, and often gives a precipitate with barium chloride or silver nitrate. Water of this description must be re-distilled from glass, and the apparatus shown in Fig. 1 may be used for the purpose. The neck of the retort is enclosed within a glass or tin tube *a*, and a current of cold water is made to circulate between the two, in order to condense the steam before entering the receiver, *g*. When the retort is used in connection with the pneumatic trough, as in the preparation of oxygen, it is important to remember that, if the burner or spirit-lamp be removed before the retort is taken out of water, the latter may rush up the neck of the retort in consequence of the contraction of the air within, and fracture may be the result. Another frequent cause of breakage is the sudden application of flame to a glass vessel containing a solid substance.

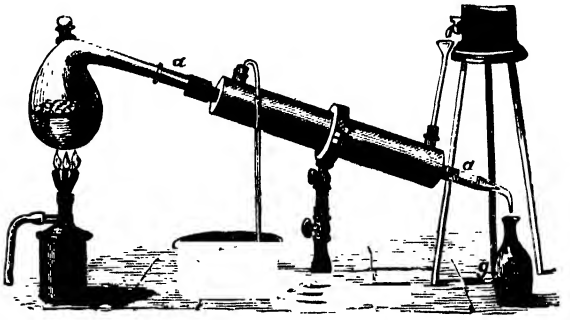


Fig. 1.—Apparatus for Distillation of Water, or of Alcohol from Wines, &c.

When a fluid is to be boiled, the vessel may be suddenly exposed to the heat without danger of fracture, as the heated particles are carried upwards by convection; but in the case of a solid, the glass must first be warmed and the heat then gradually applied. The hard Bohemian glass, of which test-tubes and retorts should be made, will stand a very high temperature, and never crack, except from the force of a collision.

Sometimes a system of three or four flasks is employed, as in the preparation of hydrogen sulphide, or sulphuretted hydrogen. Such an arrangement is shown in Fig. 2, where *a* is the bottle containing the metallic sulphide and acid employed in making the gas; *b* is the wash-bottle for purifying the gas; and *c* is the bottle containing the water to be saturated with the hydrogen sulphide. In fixing arrangements of this kind a "nest" of cork-borers is of essential service. This consists of a series of brass tubes of different bores, for the purpose of piercing corks which have to be fitted with narrow glass tubes. To obviate the necessity of piercing a cork with three holes, a bottle with three necks, called a Woulff's bottle, can be employed. These bottles are very useful in operations in which water has to be saturated with a gas, or where a gas is required to be washed previously to its collection. A three-necked Woulff's bottle is used in fitting together an apparatus for the liquefaction of sulphur dioxide, or sulphurous acid. This pungent gas is given off from burning sulphur, but is usually prepared by removing from sulphuric acid the elements of water and an additional atom of oxygen. This is very readily done by boiling the ordinary acid with copper turnings in an evolution-flask. The gas is purified in a three-necked wash-bottle and thence passes into a spiral tube which is surrounded by a freezing mixture of salt and pounded ice. Here it is condensed into a liquid, and runs into the flask below. Glass tubes may be united by short tubes of caoutchouc, which, when fitting closely, effectually prevent any escape of gas.

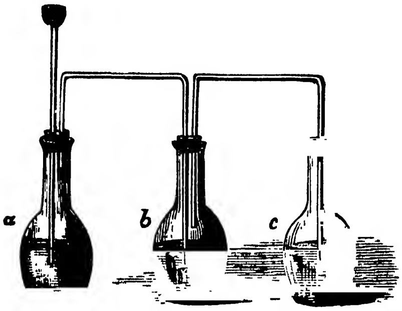


Fig. 2.—Apparatus for Preparing Solution of Sulphuretted Hydrogen.

In arranging apparatus for an experiment, it frequently becomes necessary to bend glass tubes. This can readily be done, if the tube be narrow, without the aid of a blow-pipe, by simply heating it in the flame of a Bunsen's burner, and bending it gently, when soft, to the required angle. When the tube is thick, a blow-pipe connected with a bellows worked by the foot must be used. To support retorts and flasks several kinds of stands are employed. The ordinary stand is made of iron and furnished with several rings, while a convenient form for supporting an evaporating dish, or flat-bottomed flask, consists simply of an iron ring standing upon three legs. Fig. 3 represents a wooden holder for test-tubes. This holder has a universal joint, by means of which it can be turned in any direction. Clean test-tubes should be kept in a rack pierced with holes of different sizes, for tubes of different bores. As their name implies, they are principally used in testing solutions by appropriate reagents. Their form favours the deposition and examination of precipitates, the colour of which can be readily noticed. Sometimes it is necessary to heat the tube with the contained solution, in which case a holder, such as that shown in Fig. 3, must be used. Another form, composed of two flexible strips of brass is still more convenient. Our glass apparatus would not be complete without a set of "beakers." These are lipped vessels of very thin glass, for holding hot solutions or boiling water, which could not be poured into thicker vessels. They can be heated over a spirit-lamp in the same way as flasks. Evaporating-dishes of various sizes must also be within reach. They are made of porcelain, and are used for evaporating and concentrating solutions in crystallisation, and other operations. When strong acids are to be concentrated, dishes of platinum must be employed.

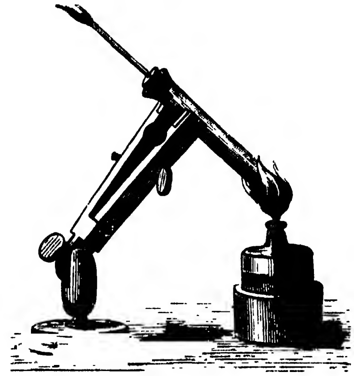


Fig. 3.—Jointed Test-tube Holder.

Amongst the most useful, though at the same time the most simple, auxiliaries in the hands of the analytical chemist, are "test papers." These are small strips of bibulous paper which have been saturated with certain vegetable tinctures, and indicate by an immediate change of colour the presence of an acid or an alkali in a given solution. They are made up in the form of little books, and a strip can be readily torn off when required. Blue litmus paper has been steeped in a tincture made from a kind of lichen (*Rocella tinctoria*) growing abundantly in the Canary and Cape Verd Islands. This paper turns red when dipped into a liquid having an acid reaction. Red litmus paper, which has been reddened by an acid, is used as a test for alkalies, which restore the blue colour. An amusing experiment may be performed by placing a drop of some acid at the bottom of a tall vessel, and pouring in a solution of blue litmus. The blue colour is immediately changed to red. The experiment may be reversed by pouring the reddened liquid into another vessel containing a drop of ammonia. The blue colour will reappear. These changes appear extraordinary to the uninitiated. Yellow turmeric paper has been steeped in a tincture made from the roots of the *Curcuma longa*, a plant growing in all parts of Bengal. Its colour is changed by alkalies to brown. It must not be forgotten that this property is possessed by some substances that are not strictly speaking alkalies. For instance, carbonate of soda is a salt, but it changes red litmus to blue: we can, therefore, only say with correctness that it has an alkaline reaction. There are other test papers, such as ozone papers, for detecting ozone in the atmosphere. These are impregnated with starch paste and iodide of potassium, and turn blue when acted upon by minute quantities of ozone. Then we have lead-papers, which turn black on exposure to sulphuretted hydrogen. These papers should be kept in a small drawer, while other drawers should be provided for small articles, such as corks, labels, platinum-wire and foil, short caoutchouc tubes, &c.

We must now take a survey of the sources of heat at the disposal of the modern chemist. The huge furnace of Mephistopheles, so familiar to opera-goers, is now a thing of the past; and in its place we have blast gas-furnaces, large gas flame burners, and the useful Bunsen's burner, which last has quite superseded the old spirit-lamp. The burner called after the celebrated chemist of Heidelberg has been a boon in the laboratory. It gives a great heat, and is altogether more convenient and cheaper in respect to consumption of fuel than the spirit-lamp. Its principle is very simple. An iron tube having an orifice near its base is fitted over an ordinary gas-burner, which is supplied with gas by means of a flexible tube connected with the gas-pipe. The air entering the orifice mixes with the coal-gas as it ascends in the tube, and the mixture is ignited at the top. This burner gives a pale-blue non-illuminating flame, owing to the complete combustion of the carbon; but the tube can be turned round so as to close the orifice, and prevent the admission of air. The flame then becomes yellow and luminous. The "rose burner" is similar in principle, but has a number of openings at the top, so arranged as to give a ring of jets. This burner gives a diffusive heat, suitable for evaporation and other operations, to which the single jet is not adapted. A much more powerful heat is afforded by Bunsen's gas apparatus for heating crucibles, in which a number of air tubes are combined and used together

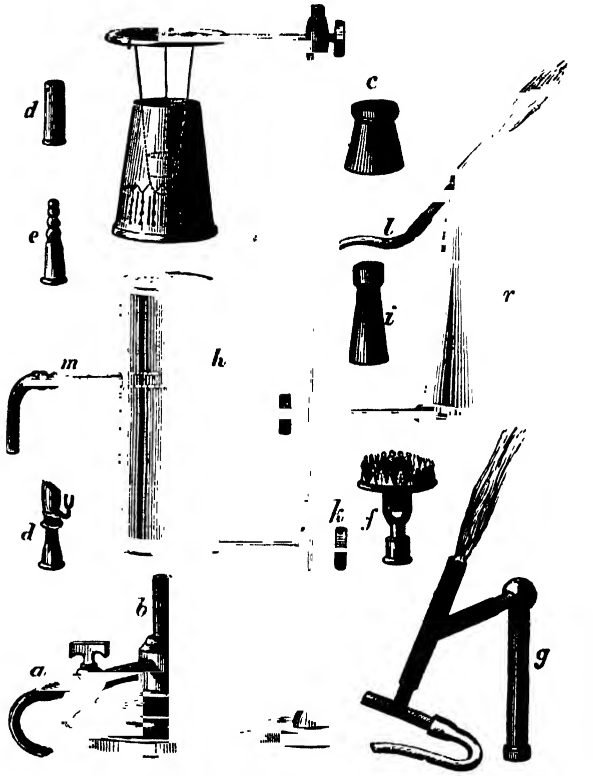


Fig. 4.—Deville's Gas Apparatus.

Air enters the apparatus by the tubes, and the gas by a flexible pipe. The whole is thoroughly mixed in the chamber, which is situated in the body of the apparatus. The mixture then passes out by a bundle of eight tubes in close contact, so as to furnish a single solid flame of a very high temperature. A movable jacket surrounds the bundle of tubes to cut off disturbing currents, and another jacket for holding the crucible to be heated is suspended from a retort-ring by platinum wires.

Professor Deville's blast gas-furnace is still more powerful. It is preferred by the French chemists, as it can be adapted to an almost endless number of operations. A variety of burners, giving flames of various shapes and sizes, can be fitted to the apparatus—a blowpipe, a blast nozzle, a rose jet, an oxy-hydrogen jet, and many others can be attached; and thus, by their aid we can heat crucibles or evaporating dishes, fuse minerals and metals, reduce metallic oxides, and even melt platinum and other refractory substances. Gas enters the tube *a* (Fig. 4), and rises by the tube *b*, which is furnished with a screw to which all the various burners shown in the figure can be attached. The burner *c*, for instance, is perforated with a circle of small holes for the purpose of giving a ring of jets, adapted for diffusive heat; *d* represents a single jet, as in Bunsen's burner; *e* is a flat jet for blowpipe experiments; *f* is an argand burner, with a gallery for holding a chimney; *g* is a burner furnished with a double-jointed movable nozzle, which can be placed in any required position, and to which is fixed a blowpipe adapted to the flexible pipe *g*.

This tube can be put in connection with a bellows, and a blast of air can be sent into the apparatus for the purpose of intensifying the heat in such operations as glass-blowing, fuzing zinc or copper, reducing metallic oxides, &c.; or it can be connected with a gas-holder containing oxygen under pressure. We shall in that case get the oxy-hydrogen blast with a heat capable of melting silver, which requires a temperature of 1873° F., or copper, which melts at 1996° F., and even gold, which does not fuze under 2016° F. *h* is a metallic cylinder open at the bottom and covered with gauze at the top, which can be lowered over the burner *b* by means of the thumb-screw *k*. A large flame is then obtained above the gauze, and its heat is augmented by connecting the tube *m* with the bellows and blowing air into it. This flame is well adapted for crucibles; *r* is a similar cylinder furnished with a blowpipe, *l*. The *hot-air bath* is another important piece of apparatus for heating purposes. Many compounds, especially those of organic origin, require to be heated or dried for some time at a constant temperature, and the hot-air bath is provided with a mercurial regulator for the purpose of securing this uniformity. Bunsen's hot-air bath and regulator is represented in Fig. 5. It is suspended against the wall of the laboratory, and heated by the gas-burner below, *d*, the distance of which from the base can be adjusted by the screw *g*. The gas enters by the supply-pipe *a*, and passes into the tube *b*, thence into the tube *c*, and is ignited in the burner *d*. Any desired temperature can be secured by increasing or diminishing the quantity of gas entering the burner; and to keep the supply of gas constant the following ingenious expedient is adopted: at the bottom of the tube *b* in the part which enters the bath a quantity of mercury is placed; a glass tube, which is a continuation of the supply-pipe *a*, passes down the tube *b* and dips into the mercury. This simple arrangement constitutes the regulator. When the supply of gas brought by the pipe *a* is augmented the heat of the bath rises, and the mercury expands in the tube *b* and increases the pressure upon the mouth of the tube *b*. The effect of this increase of pressure is to diminish the supply of gas, and at the same time to lower the temperature. On the contrary, when the supply of gas is diminished, the heat falls and the mercury contracts. The pressure upon the mouth of the tube *a* is diminished, the quantity of gas brought to the burner is increased, and consequently the heat rises. The thermometer *e* passes into the bath and indicates the degree of heat, which may, by the arrangement just described, be maintained for a considerable time at any desired point.

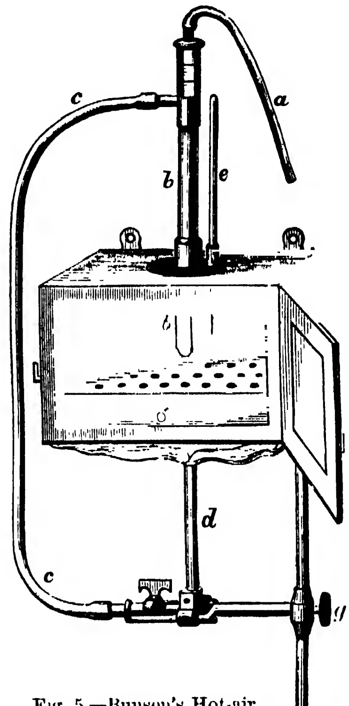


Fig. 5.—Bunsen's Hot-air Bath.

We must now say a few words respecting the use of the blowpipe, a simple instrument, but one of considerable importance in the hands of the analyst. It is simply a brass or tin tube of a conical form having a nozzle with a fine orifice inserted near the wide end. Blowpipes of japanned tin may be purchased for a trifle, and answer the purpose very well. A little practice will be necessary before this instrument can be used effectively. The blast must be kept uniform and constant, but the novice invariably stops at frequent intervals to take breath, and the effort is consequently abortive. The cheeks must be distended with air throughout an experiment, and the habit must be acquired of breathing through the nose while blowing. The difficulty at first experienced will soon vanish, and the student will be able to keep up an uninterrupted blast for a long time. The blowpipe flame is composed of two cones, an inner flame of a blue colour, and an outer yellow flame. The latter is the oxidising flame, and the former the deoxidising or reducing flame. When an oxide is exposed to the inner flame, the incandescent particles of carbon floating around it withdraw oxygen, and become converted into carbonic acid, while the oxide is reduced to the metallic state. On the other hand, if a fragment of metal is exposed to the outer flame, the oxygen of the heated air in contact with it enters into combination with the metal and an oxide is produced. In these experiments platinum wire and pieces of hard charcoal are used to support the body to be examined, and some salt, as soda carbonate, borax, or microcosmic salt (a mixture of soda phosphate and ammonia phosphate) is used as a flux. Suppose we wish to reduce a salt of lead, such as the nitrate or acetate: the salt is mixed intimately with the flux, and put into a small hole scooped in the piece of charcoal. On exposure for a few seconds to an uninterrupted blast in the inner flame, little globules of metallic lead will be produced. Oxide of lead will be formed by exposing a fragment of the metal to the outer flame.

When a solution is to be examined a borax bead is formed in the following manner:—A small hook is made at the end of a platinum wire and made red-hot in the blowpipe flame. When dipped into powdered borax a portion of the salt adheres, and will run into a bead on being again heated. If the bead is dipped into a solution of cobalt nitrate and exposed to the outer blowpipe flame a beautiful blue colour will be produced, owing to the decomposition of the salt and the formation of an oxide. Portions of any dry salt not larger than a pin's head can be melted into these borax beads, and submitted to the action of the blowpipe. Examine, for instance, a grain of copper sulphate or nitrate in this way. In the outer flame we shall get a transparent green glass, but in the inner an opaque brown glass will be produced. This action of the blowpipe affords an excellent confirming test for copper. Similarly, chromium gives a transparent glass both in the outer and inner flame, and manganese gives to the bead an amethyst tint; indeed, manganese oxide is used in the manufacture of artificial amethysts; while copper, chromium, cobalt, and iron furnish various shades of green, blue, and red for other mock gems. Some other useful additions to the laboratory remain to be noticed. Bell-jars of different sizes, plain and tubulated, are useful for experiments on gases. They are easily filled from the pneumatic trough, and can be removed by sliding under them a plate of zinc or earthenware. Phosphorus, sulphur, and other substances may be burned in these bell-jars by means of a *deflagrating spoon*, which consists of a bent wire, having a little iron cup at one end, and passing through a brass cap, which can rest upon the top of the jar and prevent the escape of gas.

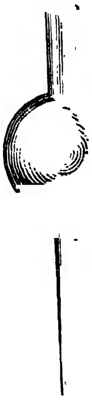
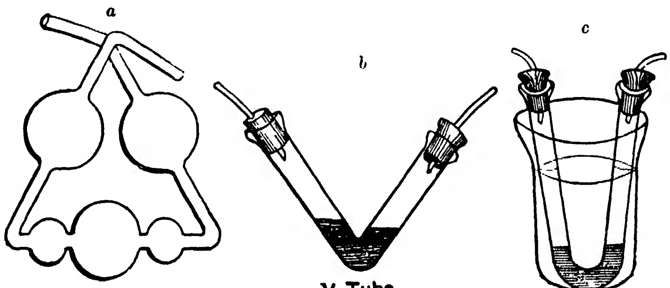


Fig. 6. Pipette.

In some experiments with gaseous compounds it is necessary to employ tall cylindrical glass vessels. In exhibiting, for example, the spontaneous ignition of copper filings by chlorine, a tall vessel is better adapted to show the descent of the red-hot particles of metal. One of the most striking experiments in chemistry is to mix one volume of olefiant, or heavy carburetted hydrogen gas, with two volumes of chlorine, and to inflame the mixture. A thick black cloud of carbon is produced, and a lurid flame passes down the cylinder. A useful little instrument for delivering water or acids by the drop is called a *pipette* (Fig. 6). When the mouth of the pipette is closed by the thumb, the pressure of the air prevents the escape of the liquid, but when the thumb is withdrawn, drop by drop exudes from the small orifice at the extremity. This instrument is very useful where a very slight excess of a reagent is to be avoided, as in the case of caustic potash, which produces a precipitate in solutions of certain metallic salts, as those of zinc, tin, aluminium, lead, and antimony, but re-dissolves these precipitates if an excess be added. Tubes bent into various forms, as in Fig. 7, are used in the analysis of gases. *a* is a potash bulb, for holding solution of caustic potash. This is used when we wish to absorb



Liebig's potash bulb. V Tube. U Tube.

Fig. 7.—Tubes used for Analysis of Gases.

carbonic acid from the air or any other mixed gas. The bulb is weighed before and after the operation, and thus the quantity of carbonic acid existing in a given volume of mixed gas can be estimated. *b* is a **V**-tube, and *c* a **U**-tube, both of which are employed to hold lumps of chloride of calcium, or pieces of pumice-stone saturated with concentrated sulphuric acid, for the purpose of absorbing the aqueous vapour which usually comes off when a gas is generated.

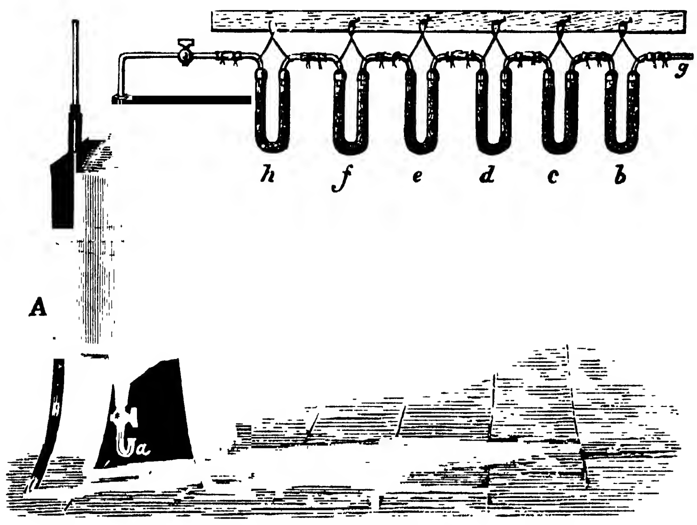


Fig. 8. Aspirator for Drawing Air through the U-Tubes.

Fig. 8 will illustrate the use of these tubes and the method of making a quantitative estimation of the carbonic acid and water in atmospheric air. A is an *aspirator*, which is a contrivance for drawing atmospheric air through the entire set of tubes. This is managed in the following way :—The aspirator, whose capacity is known, is filled with water, which is allowed to escape through the pipe *a*, turned up at the end to prevent the entrance of air. As the atmospheric air cannot find admittance to compensate for the loss of water by any other channel than the pipe *g*, it follows that it must be be drawn through the contents of the bent tubes *b*, *c*, *d*, *e*, *f* and *h*. The first three of these are filled with lumps of chloride of calcium, and the other tubes with pumice-stone, moistened with caustic potash. The increase of weight in these tubes represents the amount of water and carbonic acid present in the air under examination. In conducting experiments of this kind it is necessary to have at command a very delicate balance.

No laboratory is complete without a perfect chemical balance, which, by the way, is rather a costly instrument, and is usually kept in a glass case to protect it, not only from dust, but from disturbing draughts of air. In this balance the horizontal oscillating beam has a triangular knife-edge of agate fixed at its centre, and at the point where this rests, on the summit of the vertical brass pillar, is a horizontal plane of agate. There is another agate knife-edge at each end of the beam. Each of the brass pans is suspended by an agate plane resting upon the agate edge, and thus the amount of friction is reduced to a minimum, and the sensitiveness of the balance rendered so perfect that it will turn with $\frac{1}{10}$th of a milligramme when loaded with 100 grammes—that is to say, it will indicate the one-millionth part of the substance weighed. The durability of the balance is increased by an arrangement which permits the beam and pans to be raised from their supports, and the pressure upon the agate planes is thereby removed when the instrument is not in use. We cannot take our leave of the laboratory without glancing at certain graduated glass vessels, which appear to occupy a prominent position amongst the apparatus in the room devoted to quantitative analysis. These instruments are used in what is called *centigrade*-testing, and are known as centigrade test-tubes, or, more commonly, alkalimeters. They are usually graduated into 100 equal parts, and are used for measuring definite quantities of test-liquors in the analysis of commercial acids, alkalies, and other products. Some forms of alkalimeters are represented in Fig. 9 : *a* is provided with a grooved stopper, which allows the contents to be poured out

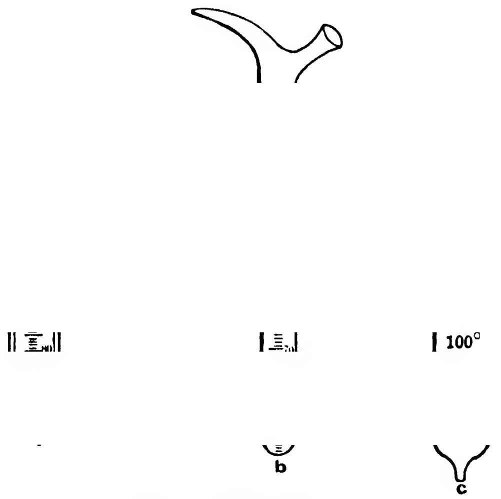


Fig. 9.—Alkalimeters.

very slowly. The lip of this and other vessels of the same kind must be greased, to prevent the liquid running down the outside. *b* is a convenient form of this instrument, which combines the pipette with the centigrade test-tube. It is a modification proposed by Mr. Binks of Gay-Lussac's pouret. *c* is a pipette which delivers exactly a hundred measures of test-liquor. Acids are tested by observing the number of measures of a standard solution of soda carbonate required to neutralise them; and alkalies are estimated by the reverse process—that is to say, by neutralising them with sulphuric acid of a standard strength. For the method of using centigrade test-tubes, the reader must be referred to manuals on practical chemistry.

It only remains to notice, amid a variety of complex instruments devised for special purposes, some miscellaneous articles, which, although they appear rather insignificant, cannot, nevertheless, be dispensed with. Here we see a number of solid glass stirrers about eight inches long, which are very useful in making solutions of salts; while in another place is a pair of iron tongs, suitable for removing hot crucibles from the furnace. Small tongs of platinum are used for holding platinum-foil or platinum cups. Files and rasps of various shapes are useful for shaping corks, and sharpening cork borers; brushes for cleaning test-tubes; mortars of glass, porcelain, and brass for pounding; iron and platinum spatulas; powder scoops, hammers for breaking minerals, safety tubes for gas bottles, funnels, fireclay and platinum crucibles, glass receivers, gas pipettes for giving definite quantities of gases, and iron bottles for making oxygen on a large scale for the limelight, are all in their appropriate places. Here, again, are some glass bottles of peculiar construction, which must not be overlooked. They are specially adapted for holding strong acids and volatile liquids, such as ammonia and the ethers. Fig. 10 represents a bottle of this kind. It has a wide neck, and instead of a stopper it has a glass cap, ground to fit the outside of the neck. It is also furnished with a pipette, having an orifice so small that it will deliver but one drop at a time, although it can be made to give many drops in succession. The pipette always remains in the bottle, and is therefore always ready for use. By the skilful use of these apparatus the chemist questions nature, and arrives at discoveries as wonderful as any which the alchemists dreamt of, and in the aggregate value productive of almost as much material wealth as that philosopher's stone which was to change the "base" metals into the basest of them all.

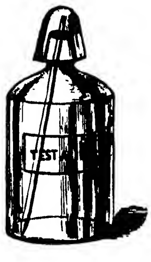


Fig. 10. — Acid Bottle with Pipette.

HOW THE INTENSITY AND DURATION OF SUNSHINE ARE MEASURED.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.

As sunshine is the source of all activity and movement upon the earth, it is a matter of some consequence that science should possess means to mark accurately the amount of it which is available for use at any given place, and to record the differences in that amount which occur from time to time and at opposite seasons of the year. For meteorologists especially the study of this subject is of the highest importance, because both seasons and climates derive from it their characteristic and distinctive features.

The first scientifically exact measure of the intensity of heat force which is exerted by sunshine was made by M. Pouillet, a French meteorologist. He devised a very ingenious and efficient instrument for the purpose, which he termed a pyrheliometer, or sun-heat measurer.* This apparatus consists of a flat cylindrical steel case, prolonged downwards into a narrow tube, as shown in A A and B B, Fig. 1.

The flat case contains a quantity of mercury, the exact amount of which has been ascertained by weighing, and it is blackened at the top (C) to enable it to absorb heat readily when exposed to the sunshine. In the interior of the apparatus a delicate thermometer is placed, so that its bulb is plunged into the mercury, while its stem is carried down into the tube, and exposed at D to admit the reading off of the temperature by means of the usual thermometric scale. The entire apparatus is capable of being attached to a post or stake of wood, by the agency of a universal joint and screw (E), and at the lower part of the stem a round disc of brass (F), of exactly the same size as the top of the cylindrical case, is so fixed that the black top of the case can be kept exposed to the direct rays of the sun by the simple expedient of placing the instrument in the position in which the shadow of the case at the top just falls upon and coincides with the round disc beneath. The black top of the case then lies exposed to the perpendicular rays of the sun.

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* The technical designation of this instrument is derived from the Greek words, *pur*, fire or heat; *helios*, the sun; and *metron*, a measure.

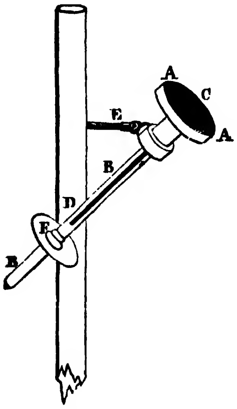

Fig. 1.—Pouillet's Pyrheliometer, for Measuring the Heat of Sunshine.

When the apparatus is duly adjusted in this way, and exposed to unobstructed sunshine, the heat from the sunbeams is rapidly taken up by the black top of the steel case, and communicated to the mercury contained within. The rise of the thermometer forthwith indicates how much warmer the mercury has become from the heat which it has received. But the blackened case not only acquires heat from the sunshine, it simultaneously shoots off into the air some portion of that which it has previously possessed. The loss, therefore, has to be taken into account as well as the gain. First, the black top is exposed for five minutes to the sunshine, and the rise of the thermometer during those five minutes of exposure to the sunshine is marked. Immediately afterwards the blackened top is screened from the sun and directed to another part of the sky, and the *fall* of the thermometer during an equal period of five minutes is noted.[*] That shows how much heat was dissipated from the top whilst the thermometer was in process of being raised by the sunshine. The two quantities—the loss and the gain—by a simple process of arithmetic, then taken together, and after a fair balance has been struck, tell what the heat of the mercury would have been after the exposure to the sunshine if there had not been this concurrent loss at the same time. The amount of loss from the exposure without sunshine has to be added to the amount of the gain from the exposure in the sunshine, and the sum-total gives the heat which has been conferred upon the known weight of mercury by five minutes of sunshine. This, accordingly, thereupon becomes a definite and intelligible measure of the heating power of the sun—at least, so far as the effect upon mercury is concerned. But the relations of heat to the various different kinds of material substance are now so well understood that this also at once tells what the gain of warmth would have been if any other substance than mercury had been submitted to the ordeal; how much, for instance, any fixed quantity of water would have been heated, or how much ice would have been melted. Carefully conducted experiments with this ingenious instrument have consequently enabled scientific experimenters to say that the perpendicular rays of clear sunshine give as much heat to any surface upon which they fall as would serve to melt a thickness of very nearly half an inch of ice in half an hour, and that if all the heat which is communicated to the earth from the sun in a year were uniformly and evenly applied over the entire extent of the terrestrial surface it would suffice for the melting within that period of a casing of ice 100 feet thick.[*] Such, therefore, is the measure of the force which is available upon the earth for the maintenance of the multifold operations of terrestrial economy that come under the observation of man. The winds, waves, rivers, and rain, the unceasing vegetable growth, and the endless activities of animated vitality are all sustained by an expenditure of sun-derived force which would be competent to melt every year a shell of ice as large as the earth, and 100 feet thick.

But the duration of sunshine at any definite spot upon the earth is more difficult to reduce to measure and rule than the immediate intensity of the sunbeam, because this has to do with an effect that is changing at every successive instant. The clouds which sweep over the face of the sky are notoriously amongst the most fitful and uncertain of the visible aspects of Nature. It is no easy task to set down in fixed terms how the sunshine and cloud divide themselves amongst the minutes of a single passing hour, to say nothing of every hour of the day and of every day of the year. The processes of photography can give no help towards the establishment of such a record, because the effects with which they deal are incident to the diffused light issuing from the clouds, as well as to the concentrated light of sunshine. The miniature fire of the focus of the burning-glass is not subject, however, to the same incapacity, because it only scorches or burns when it is the beams of the unclouded sun which are brought into play, but with it there is an inconvenience to be met with of another kind. The glass which produces the burning spot has to be continually shifted with the diurnal progress of the sun across the sky if that spot is to leave a that can be turned to account as a record of the duration of the sunshine. But, nevertheless, the burning of a track by a miniature image of the sun produced by the agency of a convex lens of glass is the direction in which the solution of the problem has been most successfully sought. The happy idea occurred to an ingenious observer some twenty-five years ago that the need to make the burning-glass travel correspondingly to the movement of the sun would be obviated if many burning-glasses were used in succession instead of one, or if a form of lens were employed which has a uniform curvature from whatever direction it is looked at, and which is, therefore, in that sense a series of lenses in one. A sphere or globe of glass is obviously such a many-faced lens. If a round ball of clear glass be hung up in the sunshine, its burning focus is formed opposite to the sun, but a little way outside of, or beyond, the surface of the globe. If the sun were shining upon a globe from the direction marked A A in Fig. 2, the focus of its concentrated rays would be constituted at B, and any combustible substance, such as brown paper, would be set fire to there by the intensity of the accumulated heat. But when the sun had travelled round in the sky so that its beams fell upon the globe from the direction C C, instead of from the original direction A A, a focus would still be formed at the same distance from the surface of the globe, and opposite to the sun, but consequently at D instead of at B. As the sun travelled round above the globe the focal point of its collected rays would sweep round beneath the globe in the opposite direction. If a screen of combustible substance, such as brown paper or wood, therefore, were arranged in the form of a hemispherical cup, such as E D B F, at a proper distance beneath the globe, the burning point would leave a charred track all along upon the paper or wood as it travelled from B to D. This plan was actually brought into operation to enable the sunshine to score a charred track upon wood by Mr. J. F. Campbell, of Islay, but he used in the first instance a hollow globe of glass filled with water instead of a solid globe, and he placed the sphere within a basin of wood, so adjusted in reference to its size and to the position of the ball that the focal image of the sun, or burning-point, always rested upon the actual surface of the concavity of the bowl as it swept along under the diurnal march of the sun.

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[*] In making a very exact and careful experiment, the case is exposed without sunshine five minutes before and five minutes after the exposure to sunshine, and the mean of the two trials is used as the estimate of the cooling or loss.

[*] "Science for All," Vol. II., p. 118.

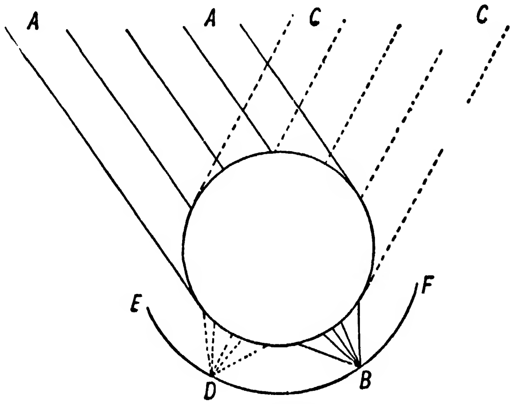

Fig. 2.—Diagram showing how Parallel Rays of Sunshine are thrown into a Focal Point by the action of a Transparent Ball of Glass.

The apparatus constructed by Mr. Campbell was placed upon the roof of the house occupied by the General Board of Health in London in 1854, and in 1857 the hollow globe of glass was superseded by a solid sphere. A new bowl of wood was provided every six months, and during that interval the burning focus traversed the bowl, and scored its track day after day in the substance of the wood, leaving a broad zone, more or less charred and more or less deeply consumed, according as more or less sunshine had been prevalent during its term of use. In the year 1873 several of the bowls that had been so exposed to the sun were transferred to the charge of the Meteorological Office, and an attempt was made by Professors Roscoe and Balfour Stewart to form a comparative estimate of the amount of burning work that had been accomplished in each half-year. In the year 1875 the apparatus was removed to the Meteorological Office at Kew, where, in the more convenient form into which it was shortly afterwards improved by the ingenuity of Mr. R. Scott, the successor of Admiral Fitzroy in the superintendence of this department of scientific work, it has since continued to furnish its record. On the 7th of May, 1876, a corresponding instrument was supplied by Mr. Campbell to the Royal Observatory at Greenwich, and from that year there have been analogous continuous records of the duration of sunshine preserved both at Greenwich and Kew.

The first point to which Mr. Scott directed his attention in his attempt to improve the capabilities of this instrument was the consideration of how the apparatus might be best made to give a distinct trace for each succeeding day, which might be removed from the instrument and kept as a permanent record of the work of that day. The device which he ultimately adopted for this purpose was the use of a strip of cardboard, which was fixed in a proper position along the inner surface of the wooden bowl in the morning, and removed in the evening. This strip then received the impression from the burning sunshine instead of the wood. A mere comparison of the several strips afterwards, therefore, gave the proportional amount of sunshine from day to day. After a little time it occurred that the bowl might be dispensed with if the strips of card were exposed in a curved frame of brass, so attached to the instrument as to enable it to be shifted day by day to meet the increasing or diminishing noon-tide altitude of the sun in the sky. Several instruments were shortly afterwards made with this adjustable semi-circle for the reception of the daily trace.

The principal inconvenience experienced in using this form of the instrument was the care which was required to place the strip of card each day in the precise position in which it must be to catch the spot of sunshine during its progress from sun-rise to sun-set. This is slightly different for each succeeding day; and although this difference of track is one that can be easily provided for beforehand by a skilful and experienced manipulator, it was nevertheless found to be desirable to fit the instrument for less skilful handling by providing it with some more ready means of making this adjustment. Professor Stokes, of Cambridge, accordingly turned his attention to the matter, and, with the help of Mr. Lecky, the meteorologist, he succeeded, in the spring of 1880, in constructing an instrument which appears to accomplish all that can be required for the prosecution of this branch of physical research, and which promises henceforth to make the comparison of the duration of sunshine in different localities one of the routine proceedings of meteorological observation.

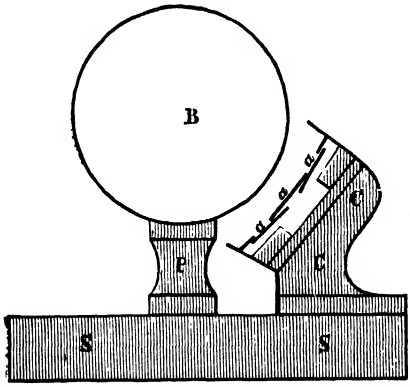

Fig. 3.—Diagram illustrating the arrangements of Professor Stokes's Instrument for recording the Duration of Sunshine (half size).

In the perfected instrument, which science owes to the ingenuity of Professor Stokes and his assistants, a carefully turned sphere of crown glass (B) is placed upon a brass pillar (P), fixed on a solid slab of slate (S S), as is represented in the accompanying diagram (Fig. 3). The slab also sustains a concave stand of brass, shown in transverse section at C C, so formed as to be able to hold the card strips (*a*, *a*, *a*) exactly where the sphere forms its focal spot for parallel rays of sunshine incident upon it at the opposite side.

The form of this concave stand or cup is more fully represented in Fig. 4, where S S again indicates the slab of slate, P the brass pillar hollowed out at the top for the reception of the sphere, and C C the concave basin-like holder, or frame, with one of its graduated cards prepared for the registration of the sunshine introduced in its proper place at A. The glass sphere (B in Fig. 3) is four inches in diameter, and when the instrument is in use forms a focal image of the sun just 0·89 of an inch beyond its outer surface (at *a*). The proportions of the stand are therefore so arranged that when the glass ball is in its place upon its pedestal, the cardboard strip (*a*, Fig. 3, and A, Fig. 4) is everywhere just 0·89 of an inch away from its surface. The globe having a diameter of four inches, the cup is moulded upon a diameter of 5·78 inches. When the instrument is arranged for its work, the slate slab is fixed so that it is horizontal from east to west, and so that the focal image of the sun formed by the ball at the instant of noon falls upon a central line engraved upon the inside of the cup (M, Fig. 4). The stand represented in the figure is one which is prepared to be used in the latitude of London. But for other parallels of latitude more towards the north or the south, the inclination or tilt of the cup upon the slab is altered to a corresponding angle to meet the case. The card strip for the day, when the instrument is in use, is pushed into its groove until the central transverse line (marked *xii.*) exactly coincides with the meridian-line M, already alluded to as engraved upon the brass.

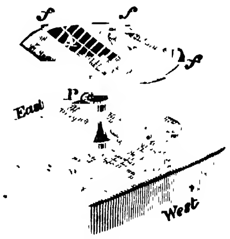

Fig. 4.—Stand for Professor Stokes's Instrument for recording Duration of Sunshine.

The instrument having been duly adjusted, with its ball upon the pedestal and facing the south, a focal image of the sun is cast upon the card and burns itself in. As the sun travels across the sky from east to west the focal image moves along in the opposite direction upon the card, and in doing so scores its track in upon the card, whenever the sun is clear, by a charred mark, but leaves the card white and unstained whenever the sun is screened by clouds. The extent and position of the charred track, therefore, at the close of the day shows the proportional amount of sunshine and cloud, and how these were distributed amongst the several hours of the day. The following diagram (Fig. 5) represents the appearance of the charred track upon a card, with its dark trail corresponding with the presence of sunshine, and with the intervening unburnt intervals corresponding with the periods of cloud.

The perpendicular short lines traced upon the card indicate the space over which the focal point travelled each half-hour of the day, from five in the morning until six in the evening, every third hour being marked as vi., ix., xii., iii., and vi.

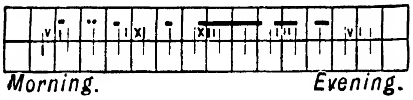

Fig. 5.—A Day's Record of Sunshine, taken by the instrumentality of Professor Stokes's Apparatus.

Thus the first dark spot shows that there was sunshine for nearly a quarter of an hour soon after six. The two small dots indicate that the sun broke faintly through the clouds for two brief intervals between seven and eight; and the long trace commencing about xii. intimates that there was continuous sunshine from a quarter of an hour before twelve until a quarter-past two.

The strip of card which is shown in position in the stand in Fig. 4 is the one which is used at those parts of the year which intervene between summer and winter. At the equinoxes—that is, on the 21st of March and the 21st of September—when day and night are of equal length all over the earth, the sun's focal track travels directly along the central line of this card from end to end. But the track gets shifted nearer to the upper edge of the card (as shown in Fig. 5) as the altitude of the sun declines, and nearer to the lower edge as the altitude is increased. The card, which is an inch and a half wide, is so broad that it serves altogether between edge and edge for forty-one days—that is, from the last day of February until the 10th of April in the spring, and from the 2nd of September to the 13th day of October in autumn. For the other parts of the year, the winter season, which extends from the 14th of October to the 27th of February, and the summer season, which lies between the 11th of April and the 1st of September, two other and slightly narrower strips are used, and it is by this very simple expedient of shifting the position of the card with the changing season of the year that the large range of the sun in altitude between midsummer and midwinter is provided for. It is this expedient, indeed, which constitutes the cardinal recommendation of this improved form of the instrument. The diagrams in Fig. 6 represent to the eye the different forms in which the strips have to be cut to suit them for the different parts of the year, namely, for the summer, the equinoctial, and the winter periods. The summer strip is long enough for use during eighteen continuous hours of sunshine, but the winter strip only affords the space for twelve hours' register. The equinoctial strip provides for the requirements of the days that do not much exceed fifteen hours in length. These three strips all adjust themselves very nearly to the inner surface of the cup when they are slid into their proper grooves. But there are different grooves provided for each of the three different kinds of cards. The accompanying figure (Fig. 7) shows how the grooves are arranged upon the inner surface of the cup to receive the strips of card.[*] The groove from 1 to 2 provides a place for the long slip of summer, the groove from 3 to 4 accommodates the equinoctial strip, and the groove from 5 to 6 receives the shortest strip, belonging to the season of winter. The grooves, it will be observed, are so arranged that their flat surfaces overlap at *o* and *o*, so that the track of the focal image of the sun may not fall upon

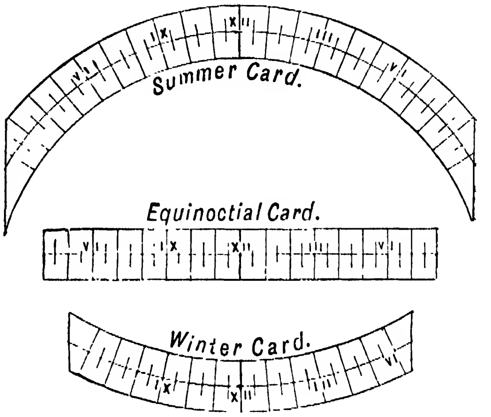

Fig. 6.—The form of the Three Strips of Cardboard which are used for receiving the Register of the Sunshine Tracks at different seasons of the year.

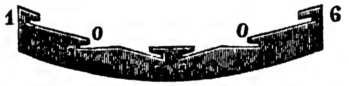

Fig. 7.—Showing the Arrangements of the Flanges and Grooves under-cut into the Substance of the Brass Cup to receive the Strips of Card.[*]

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[*] This is shown also upon the edges of the cup at *f f*, in Fig. 4.

an edge, or join, just when one season is passing into the next. The surfaces of the cards are still flat, like a strap, from edge to edge, when they are slipped into their place in the concave bed of the cup. The focal point, which is formed by the glass sphere, on the other hand, traverses a path that is curved, and concentric with the surface of the vitreous globe. The transverse surface of the card departs from the curved path of the focal image of the sun, as the line *a b* in the annexed figure (Fig. 8) departs from the curved line, *c d*. But the difference of the two tracks is practically so small for the space that is comprised within the breadth of the card, that no imperfection is caused in the register on that account. The utmost amount to which the focal point can be raised or bent away from the flat surface of the card does not exceed the $\frac{1}{72}$nd part of an inch, whilst the focal spot burns sharply, and causes a well-defined brand through a depth of one-tenth of an inch. White millboard, tinted with charcoal or coloured with Prussian blue, is found to give the sharpest trace under the charring influence of the concentrated sunshine. Blue-tinted slips, transversely graduated with white lines, are, however, upon the whole, held to give the best results.

Fig. 8.—Showing how the Curved Path of the Focal Image of the Sun deviates from the Flat Plane of the Card.

Some little care is required to adjust the instrument so that the spot of concentrated sunshine runs accurately along the card from end to end. The proof that the adjustment has been properly made is that the burnt track comes out parallel with the nearest edge of the card, as represented in Fig. 5. When the accurate position has once been secured the instrument may be permanently fixed, and no further care will then be required than that which is involved in changing the card at the end of the day. The interval between the hour lines traced transversely upon the card, or, in other words, the distance traversed along the card by the burning spot in each hour, is three-quarters of an inch.* The hour lines are parallel to each other upon the equinoctial cards, but they are slightly convergent radial lines upon the summer and winter slips. The straight equinoctial cards have to be used in March and the first twelve days of April, and in September and the first twelve days of October; the long summer or short winter curved cards are employed during the remaining parts of the year. The equinoctial card, when resting in its place in the grooves of the cup, forms a segment of a flat circular ring. It is a portion of a cylinder, having a semi-diameter of 2·89 inches. The summer and winter cards, when resting in their places, form portions of the surface of a cone. If *e* in Fig. 9 be taken to represent the centre, and *s s* be conceived to be a part of the circumference of the glass sphere, then *a b*, *b c*, and *c d* would represent the positions of the winter, the equinoctial, and the summer cards.

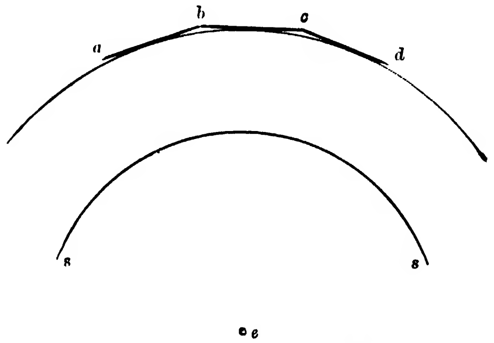

Fig. 9.—Showing in Section the Position of the three different Cards up to the points of the intersection of their Planes at *b* and *c*.

The three lines, *a b*, *b c*, and *c d*, together constitute a continuous track, which nowhere deviates more than the $\frac{1}{72}$nd part of an inch from a circular arc inscribed round *e*. The three lines from *a* to *d* correspond to a circular arc of 48°, which is slightly more than the range which the sun traverses in the sky between its high summer and low winter meridian or noon-tide, altitude.

An interesting comparison has been made by Mr. Whipple, the superintendent of the Kew Observatory, between the records of sunshine taken in 1878 at Greenwich and at Kew, which very well illustrates the kind of service these new instruments may be expected to render. Out of the 4,380 hours during which the sun was above the horizon in that year, there were 1,427 hours of actual sunshine at Kew and 1,256 at Greenwich. This difference is mainly due to the circumstance that Greenwich lies to the south-east of London, with numerous large manufactories of various kinds immediately on its north side, whilst Kew is to the west of London, and remote from all large smoke-producing establishments. That such is the case is amply proved by the fact that the relative preponderance of sunshine is materially influenced by the direction of the wind. With north, north-east, and south-west winds, Kew has but a very slight advantage over Greenwich in the matter of sunshine; with east and south-east winds, Greenwich is more sunny than Kew; but with west, north-west, and north winds, Kew gets considerably more sunshine than Greenwich. The ultimate balance is so much in favour of Kew on this account that it enjoyed 171 more hours of sunshine than Greenwich in 1878. Mr. Whipple represents the preponderance of sunshine at Kew, and the influence of north and west winds in establishing that preponderance, by means of a diagram, which is reproduced in the accompanying figure (Fig. 10).

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* In exact figures, the 0·754th part of an inch.

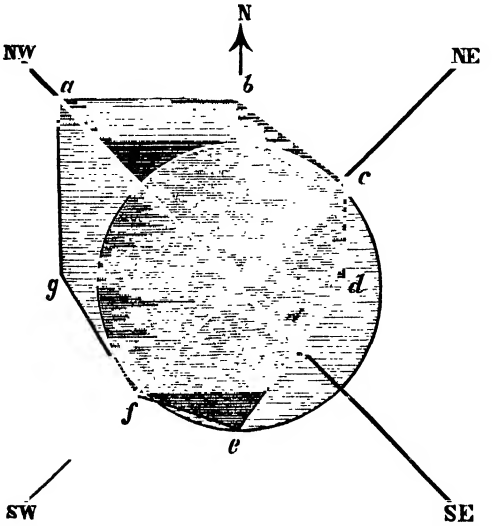

Fig. 10.—Representing the Proportional Quantities of Sunshine experienced at Greenwich and Kew in 1878.

The circular area is to be taken to express the quantity of sunshine for the year at Greenwich, and the multi-angular figure, *a*, *b*, *c*, *d*, *e*, *f*, *g*, is to be regarded as the quantity for Kew.

The cross lines, N.W., S.E., and N.E., S.W., are intended to indicate the direction of the wind. The chief preponderance of the supply at Kew coincides, it will be observed, with the prevalence of the north-west wind.

The daily allowance of sunshine, reduced to an average for the entire year, was 3·3 hours at Greenwich and 3·6 hours at Kew.

The number of hours of sunshine at the two places in each month of the year was that which is given in the following tabular summary.

Hours of Sunshine.

	At Greenwich.	At Kew.
In January	18·7	38·7
February	36·4	72·5
March	99.3	101·1
April	71·8	74·9
May	147·1	140·5
June	267·1	223·2
July	167·3	183·5
August	158·6	203·7
September	105·6	133·3
October	101·1	120·2
November	56·6	81·3
December	27·0	54·5
Total	1,256·5	1,427·1

From this table, it will be seen that May and June were the only months in the year 1878 in which the allowance of sunshine at Greenwich was in excess of that at Kew.

THE ZODIACAL LIGHT.

By John I. Plummer, M.A., F.R.A.S.,

Late Astronomical Observer to the University of Durham

UPON a moonless night in the early spring, and several hours after the sun has set, we cannot fail to notice a conspicuous phenomenon which then makes its appearance near the western horizon. Rising in an oblique direction to a considerable elevation is a hazy cone of soft light, that might be mistaken, but for its definite form and the lateness of the hour, for the last fading gleams of twilight (Figs. 1, 2). In brilliancy it about equals the Milky Way, and like it, also, its position among the stars is fixed, so that it gradually sinks down with them as evening advances, but without any diminution of lustre other than may be caused by the haziness of the sky. Although the position of the apex of the cone may be determined with some precision, and the direction of its axis is distinguishable with some accuracy, the outline fades so imperceptibly into the blue expanse of the heavens that it is impossible to trace with certainty its full extent.

At the opposite season of the year a precisely similar phenomenon may be witnessed upon the other side of the sun or before sunrise. This has been well and poetically termed the False Dawn by the inhabitants of Eastern countries, whose skies admit of its frequent observation. A little consideration will show us that each of these cones of light must exist on either side of the sun at all seasons of the year, and that nothing prevents us from so observing them but the peculiar position in the heavens that they may occupy and the prolonged twilight in northern climates. The latter especially, equally with the light of the moon, is fully sufficient to mask so ill-defined and hazy an illumination, and is a frequent cause of its invisibility. We may therefore be prepared to hear that the zodiacal light forms a more easily distinguishable feature in tropical regions, where the duration of twilight is less, and where the direction of the axis of the cone is never less favourably situated than it is in the month of March in England. There is, however, insufficient evidence to show that it is either more brilliant or more extended than it is with us.

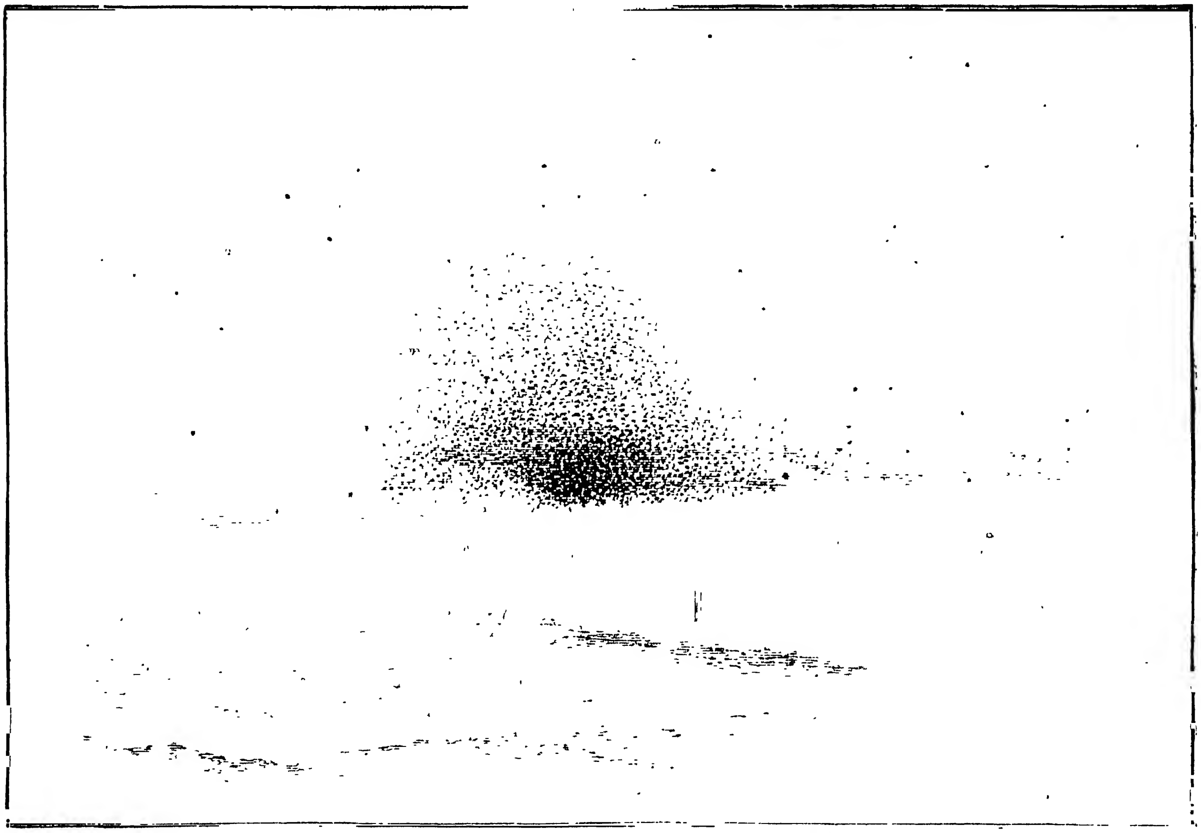

Fig. 1.—The Zodiacal Light as observed at Orsay, France, in March, 1874.

Upon a few occasions, however, a more complicated aspect of the zodiacal light has been witnessed. Humboldt has put it on record that during his sojourn in South America he has seen at the same time, at or near midnight, the illuminated cones on either side of the sun, and his observations have been confirmed by others. What this implies is that the apex of the western cone has risen before the eastern one has set, and that the entire stretch of these wing-like appendages to the sun occupies more than 180° of longitude, or half the vault of the heavens. Such simultaneous appearances, while they give us a better idea of the form and actual extent of the zodiacal light, are exclusively to be seen near the equator, for, as we shall see later on, the season most favourable in temperate climates for seeing the eastern portion would be the most unfavourable for seeing the western, and *vice versâ*. By admitting their correctness, however, we are brought to the important conclusion that, occasionally at least, the matter composing the zodiacal light extends from the sun as far as, or even farther than, the earth itself, *i.e.*, that its diameter exceeds 180,000,000 miles. Whether this is a permanent condition may perhaps be doubted, but it is beyond dispute that the orbits of Mercury and Venus are always included within its limits.

Several observers concur in stating that the colour of the zodiacal light is decidedly yellow or orange, though to ordinary eyes it generally appears of the same pale white which has given to another and entirely different phenomenon the name of the *Milky* Way. If, as we shall find reason to believe, its light is derived exclusively from the sun by reflection, we cannot expect that it would be possible readily to detect the slight excess of yellow which distinguishes the light of that body.

The common axis of the cones of light, whenever they are visible, occupies an invariable position in the heavens, and is either precisely upon that great circle of the sky which is called the ecliptic, or lies so nearly thereto that it is difficult to decide whether it may or may not be inclined at a small angle to that plane. In this fact we have an indication of its planetary nature, for it will be remembered that all the planets revolve round the sun in orbits that lie very near this plane. We have also the explanation of its apparently capricious character, as the ecliptic, unlike other great circles, is variously inclined to the horizon at different seasons of the year.

As this most important circle is the course apparently described by the sun among the stars during the year, and is the actual path which the earth itself would appear to trace out if its motions were viewed from the sun, we may perhaps advisedly give some means of identifying its position. If about the time of the vernal equinox (March 21) we take our station shortly after sunset, we may easily trace out the ecliptic from a knowledge of the position of the celestial equator. This latter circle spans the heavens from the east to the west point of the horizon, rising as far above it in the south as is equal to the co-latitude of the place (90°—the geographical latitude). The other half of the equator, the continuation of this curve, is of course below the horizon. It is, in fact, the diurnal path of the sun during the twenty-four hours upon this day of the year. Now the ecliptic, along which we shall find the zodiacal light extending itself, and near which will be found all the major planets, is a circle passing similarly through the east and west points of the horizon on this day and hour, and still further elevated in the south portion of the sky by 23½°. Thus the zodiacal light at this season in the evening rises from the western horizon at a considerable angle, approaching to perpendicularity, and boldly separates itself from the decaying twilight. At the autumnal equinox, however, the other half of the ecliptic is above the horizon at the hour of sunset, the half that dips *below* the celestial equator by the same angle of 23½° and the direction of the zodiacal light will make but a small angle with the horizon, and will thus fail to free itself from the haze and twilight that lingers near the horizon in temperate and particularly in insular climates. The direction of the axis of the cone with reference to the horizon varies therefore to the extent of 47°, and in the latitude of London it may amount to 62°, or may fall as low as 15°, the maximum angle corresponding to the eastern extension, or portion visible after sunset, in spring, and to the western extension, or portion visible before sunrise, in autumn.

The true form of the body, whatever it may be, that is thus seen on either side of the sun whenever his resplendent orb is hidden may now be comprehended. We have but to regard it as a flattened disc or lenticularly formed body viewed edgewise from the earth,—an enormously extended envelope of the sun, possibly of extreme tenuity, but none the less an integral portion of that body, which exists only in a definite direction or upon the plane of the ecliptic. From observations that have been made during the total eclipse of the sun visible in America in 1878, there is even reason for believing it to be a portion of the solar corona,* while its strangely flattened form reminds us forcibly of the rings that surround the planet Saturn, or of the figure which, according to the celebrated hypothesis of Laplace, the solar nebula, and each of the planets that separated themselves from it, must have assumed previously to their formation into solid bodies.†

Having been able to identify the zodiacal light with the sun, it will be well next to inquire whether it is affected by any of the changes to which that body is liable. The principal of these changes, so far as at present known, is an alternation of seasons of activity and of comparative rest in the eruptive forces of the sun, as indicated by the greater or lesser number of spots upon his surface. Though subject to slight irregularity, these periodical variations recur upon the average at intervals of about eleven years (Vol. I., p. 319). Unfortunately the zodiacal light has not been watched with sufficient care to enable us to say whether it waxes and wanes in complete sympathy with these forces, but a strong suspicion exists in the minds of those who have paid some attention to the subject that its brightness is variable. There can be no doubt that in 1874, when sun-spots were numerous, the zodiacal light was much more conspicuous than in 1880, when these spots were rare. From the observations on the solar corona which have been assiduously made during the last twenty years, whenever a total eclipse of the sun has rendered them possible, there is little doubt that its extent and brilliancy vary in a marked manner with the intensity of solar activity, and this may fairly be regarded as strongly confirming the suspicions already entertained.

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* "Science for All," Vol. II., p. 83.

† "Science for All," Vol. II., p. 116, Fig. 7.

That these two phenomena are either identical or very closely associated is not only shown by the observations mentioned in the paper previously referred to, but also by a similarity of spectrum. The inner portion of the corona is distinguished by some very remarkable bright lines, one of which—and, indeed, the most conspicuous of them—is a yellow-green line, which cannot be identified as appertaining to any known terrestrial element, but towards the outer portion these lines one by one fade out, and are replaced by a faint continuous spectrum, in which no dark absorption lines can be seen. It is probable that they exist, and that the light itself is merely reflected sunlight, in which case it would be crossed by all the fine dark lines that characterise the solar spectrum. In the faint light of the corona, after it had been still further weakened by its dispersion by the prisms, it is not to be expected that such delicate lines could possibly be traced. As the polariscope gives the like evidence, we are justified in concluding that while the inner part of the corona is self-luminous the outer portion is not, but is capable of reflecting a proportion of the fierce light that shines upon it; and further, that the extreme limits of the self-luminous region shine by virtue of a single line on the confines of the green and yellow of the spectrum.

The spectrum of the zodiacal light has been investigated by two able spectroscopists, and although their results are opposed to each other, neither is contrary to the theory which we have already laid down. Dr. Angstrom finds that the light is composed mainly of the bright line for which we have no terrestrial equivalent, and Professor Piazzi Smyth that it is a faint continuous spectrum, without lines, either bright or dark, in all respects similar to that of the outward part of the corona, or of faint reflected sunlight. The latter authority has explained the discrepancy on the ground that the observations of Angstrom having been made in the latitude of Stockholm, where the Aurora Borealis is of so common occurrence, have been vitiated by the presence of that light, or, in other words, that the spectrum he has observed is one of the lines of the Aurora, and that the faint continuous spectrum proper to the zodiacal light he has overlooked. Though this explanation is quite allowable and has been generally accepted, it would seem more complimentary to the discrimination of the veteran spectroscopist to suppose that he had hit upon the interior part or core of the zodiacal light, from which the yellow-green line had not entirely faded, while his later competitor, in the more favourable situation of Palermo, being under no necessity to seek out the most conspicuous part, had failed to detect it.

It is necessary to point out that this explanation of the nature of the zodiacal light is one that has only recently found favour with astronomers, and that the more common theory has been that the sun is surrounded by myriads of meteoric bodies slowly gravitating in spiral orbits upon his surface, after having been detached from the trains (not tails) of the numerous comets that have passed round him. Such bodies certainly exist in the near neighbourhood of the sun, and each will reflect a small quantity of solar light, just as an exceedingly minute planet might do, but it is doubtful whether they would be able in the aggregate to affect the eye with the brilliancy of the zodiacal light. But the main difficulty that this explanation has to encounter is, that whereas comets pass round the sun from every direction of space, and thus furnish that body with these attendants on all sides, the zodiacal light is derived from one particular and somewhat narrow region only.

On the other hand, if we regard the light as being reflected by an extension of the gaseous or cloudy corona, we are met by the difficulty that such a form of the solar atmosphere is opposed to our ideas of the behaviour of gases under ordinary circumstances, and we are bound to admit that further knowledge of the subject is loudly called for. Of the two difficulties, no doubt the latter is to be preferred, as more likely to submit to a legitimate explanation, and which is equally required whether the theory is correct or not.

An atmosphere that extends so far should certainly be of an exceedingly rarefied description, and that it is so we have some evidence. As already stated, the two interior planets, Mercury and Venus, have their orbits almost entirely included within its limits, and yet we are unable to detect the slightest variation in the form of these orbits, consequent upon the impediment to their motions which even a medium of extreme tenuity would be able to produce. The general result to be anticipated from a medium capable of offering some resistance to the motion of a planet would be that the orbit of the latter would tend to contract, that the planet would revolve round the sun at a less mean distance than formerly, and hence, that it would perform its journey in less time. This effect, too, would be of a cumulative character, since the cause would be constant, and after the lapse of many revolutions would become apparent, however small it might be, if the rarity of the gaseous or cloudy obstruction were not beyond our ordinary conceptions. It is, therefore, certain that solid, dense, and comparatively small bodies like the planets Mercury, Venus, or the Earth are able entirely to disregard the slight opposition they may encounter. Comets, however, whose mass is much smaller, and whose magnitude is more considerable, do not necessarily enjoy the like immunity. Of the seven periodical comets, whose frequent returns have enabled us to watch their motions narrowly, one has certainly presented to us the peculiarities of a body that suffers some retardation of motion in its movements through space. This comet, which is known as Encke's, has a period of little more than three years, which is

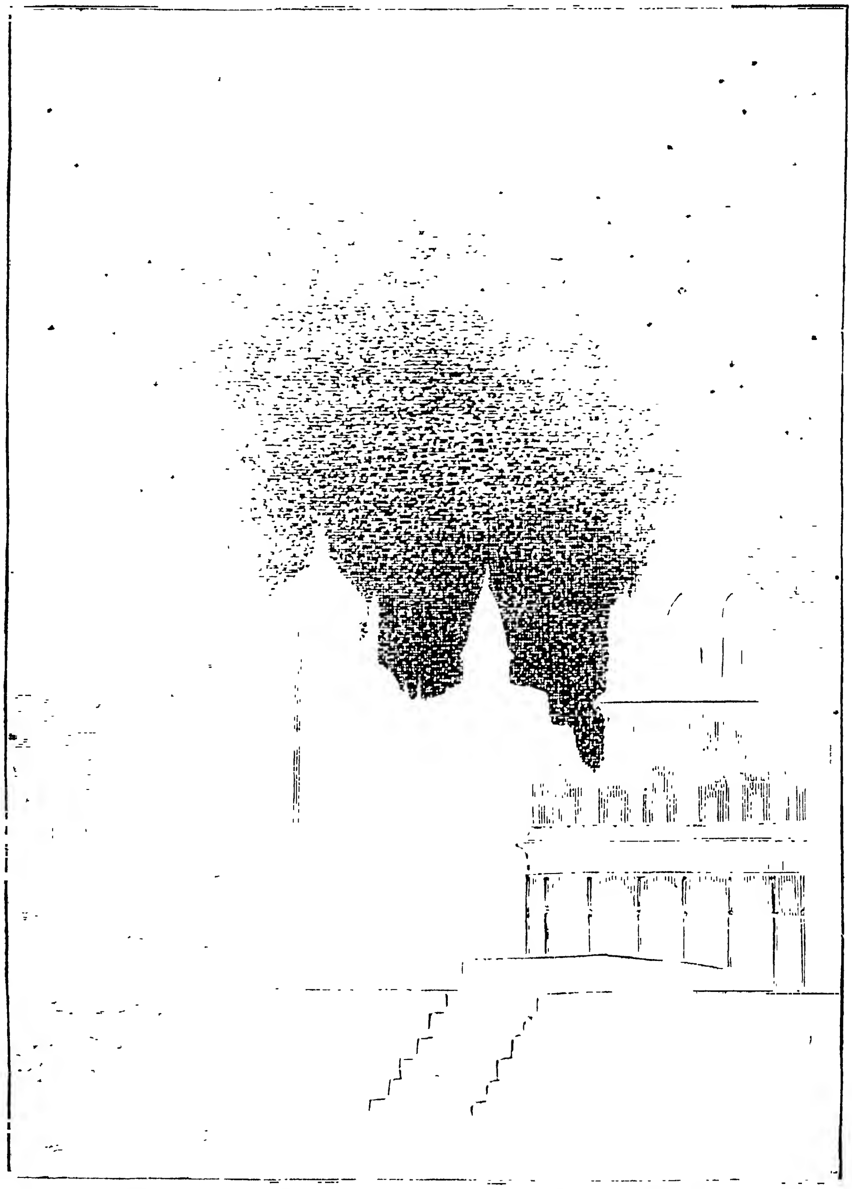

Fig. 2.—The Zodiacal Light as observed in India at the end of December, 1874.

being slowly reduced at the rate of about two hours during each revolution. As there is no cause known capable of explaining this fact in accordance with the law of gravitation, it was long since suggested by the illustrious astronomer whose name it bears that there must exist in space a "resisting medium," opposing the free movement of such bodies, and which is too attenuated to make its presence known to us in any other manner.

Although this solution of the difficulty has been generally adopted, it is not usually connected with the zodiacal light; yet it is important to notice that the comet which exhibits this peculiarity is precisely that one of the seven which approaches the sun most nearly, and thus passes through what we must regard as the denser part of the zodiacal extension of the corona. It would therefore be the most affected by retardation, which is practically insensible in all the other cases, if we except a suspicion that has recently been entertained of a still more minute reduction of period of a second member of this family of comets.

Meagre as our information is upon the subject of the zodiacal light, we may look upon the following facts as certainly known regarding it:—1st, That it is constantly visible on either side of the sun, and is only hidden or masked in temperate climates when its position in the heavens is favourable to its being confounded with the fading twilight. 2nd, That it is in the form of a disc or lens, of which the sun occupies the centre; that the diameter of the lens occasionally exceeds 180,000,000 miles, and perhaps seldom falls short of 150,000,000 miles, and that its thickness, though unknown, is not considerable in comparison therewith. 3rd, That its position in the heavens is invariable, and either coincides with the plane of the earth's motion or lies very close to it.

It is to be considered as less certain, though highly probable, that it varies in brilliancy, possibly in dependence upon the recurring periods of sun-spot frequency, but that it shines with equal lustre from whatever portion of the earth it is observed. It is also very likely that it consists of a peculiar extension of the ordinary corona or exterior atmospheric envelope of the sun, the same that has been traced during total solar eclipses to a distance of five millions of miles from the sun.

While the spectrum of the zodiacal light may not have received all the attention it deserves, it must be admitted that it is not a hopeful question for further inquiry, owing to the faintness of the light itself, and still more to the continuous form of its spectrum. But it is abundantly proved that if gaseous, the matter of the zodiacal light must be of extreme rarity. The evidence deduced by the spectroscope points with certainty to the fact that it is merely reflected solar light, and that probably no portion is self-luminous.

On the other hand, the theory that it consists of meteoric matter slowly subsiding upon the solar surface, or until the heat to which it is subjected is sufficient to volatilise the constituents, although it has been frequently advocated, cannot be held so satisfactory as that previously shadowed forth. That such meteoric matter exists, and doubtless performs important functions in the solar system, is nevertheless a supposition on which the hypothetical character of the zodiacal light need not necessarily throw any doubt.

A PIECE OF AMBER.

By F. W. Rudler, F.G.S.,

Curator of the Museum of Practical Geology, London.

NOTHING would seem to be easier than to decide off-hand whether any natural object which happens to fall under our notice should be classed in the animal, in the vegetable, or in the mineral kingdom. Yet the student of natural science soon finds that these so-called "kingdoms of nature," instead of being sharply separated one from another, are surrounded by frontiers of a very unscientific character. The wall that was supposed to form an impassable barrier turns out, upon close inspection, to be the frailest possible fence, which, with the advance of knowledge, has to be broken down first at one point and then at another. So intimate is the connection between the animal and vegetable worlds, that it occasionally becomes a nice question to determine whether a given organism should find its place in the one sphere or the other, or should not rather occupy a neutral border-land between the two. But surely no such difficulty can possibly arise in the case of minerals! In the mineral world we come in contact with bodies which not only have never possessed life, but, so far as we can judge, have been produced without the operation of any living agency. Nevertheless, the mineralogist is not altogether free from embarrassment. Like the zoologist and the botanist, he finds it impossible to draw a hard and fast line around the objects of his study, and there are times when he is perplexed to know whether he should, or should not, include a given substance in the mineral kingdom. Take, for instance, a piece of *amber*. Is it to be called a mineral or not?

A piece of amber is so familiar an object that it is needless to occupy a single line in describing its appearance or its properties. If we have not often seen the amber in its rough state, we at least know it well enough when worked into ornamental forms. The string of amber beads, or the mouth-piece of the meerschaum pipe, will furnish specimens to be found in almost every household. So beautiful a substance is naturally claimed as an ornamental stone by all writers upon gems; it is described in our standard treatises on mineralogy, and it figures in every mineralogical system. Moreover, in some parts of the world the amber is dug out of the earth, and even systematically mined for, just as any other mineral substance might be worked. All this looks very much as though we should be justified in regarding amber as a true mineral. And yet it needs but a slight examination of the body to suggest that the relations of amber lie rather among vegetable products than in the mineral world.

If we are in doubt about the nature of any given substance, the safest course is to look for some other substance, of known origin, which resembles it so closely that a comparison may be fairly made between the two bodies. In this way we may be able to argue from that which is known to that which is unknown, and such an argument from analogy is perfectly legitimate in any scientific inquiry. Let us, then, seek for some amber-like substance, of whose nature and origin we really do know something, in order that our knowledge of this body may throw light upon the history of a piece of amber.

When it is required to produce an imitation of amber, the manufacturer does not substitute any other mineral substance, or even a piece of yellow glass, but he has recourse to some of those resinous bodies which are brought into this country for the use of the varnish-maker. The favourite substitute for amber is either *copal* or *gum animé*. Samples of these bodies may be obtained from a chemist, and on placing them by the side of a piece of amber the similarity is unmistakable. In colour and lustre, in transparency and refractive power, in hardness and density, they run so close together that it often requires a good judge to distinguish between them, especially if the specimens happen to be polished. The amber, it is true, is rather harder, and less brittle, so that it is more easily worked in the lathe; but such differences escape superficial observation. Moreover, these resinous substances agree with amber in being fusible and combustible bodies, and in being capable of solution in the same liquids. Amber varnish, for example, may be made by dissolving amber in hot oil and oil of turpentine; and in like manner copal varnish may be made with the same solvents. Again, the chemist finds on analysis that the amber, the copal, and the animé have, speaking broadly, the same ultimate composition. All these bodies contain only the three elements called carbon, hydrogen, and oxygen—elements which are not characteristic constituents of minerals, but are, on the contrary, extremely common in vegetable products.

In fact, the copal and the animé are known to be resinous bodies which have exuded from certain trees. In many parts of the world the formation of these bodies may be witnessed in the forests, just as the exudation of gum from a plum-tree may be witnessed in our own garden. Knowing, then, the vegetable origin of copal, we may fairly su a similar origin for amber. And this suspicion is converted into something like certainty when we examine the subject more narrowly.

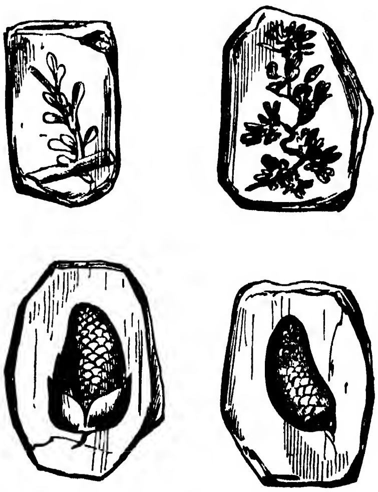

Fig. 1.—Vegetable Remains in Amber.

On looking over a large number of pieces of amber, we may occasionally find one which encloses a fragment of vegetable matter, such as a bit of bark or a morsel of a leaf. Some fine examples of these vegetable enclosures are represented in Fig. 1. More frequently, however, the included bodies are the remains of insects and spiders, sometimes in a singularly beautiful state of preservation. A few typical forms are shown in Fig. 2.

The "fly in amber" has come to be a proverbial expression, and has furnished the poet with many a metaphor. How such an object got into the amber is not more puzzling than the famous problem as to how the apple got inside the dumpling. The enigma is immediately solved by examining a number of pieces of copal and animé, for in some of these we may be sure to find enclosures of almost the same kind. In the case of these resins, it is clear that the substance when in a liquid state flowed over the surface of the tree from which it was exuded, and having entangled any little insect which happened to be within reach, slowly hardened around it, and thus sealed it up in a delicately-tinted transparent shrine. Exactly the same kind of action explains the origin of the flies in amber. They likewise must have been entrapped when the enveloping substance was in a liquid condition; and we infer that the liquid amber when first poured out must have been of tolerably thin consistency, since it has allowed the most delicate parts of the insect to be preserved in an almost uninjured condition. The occasional presence of a wing or a joint of the leg at some distance from the body of the insect tells of the hopeless struggle which the imprisoned creature must have made to free itself from the viscous medium in which it was destined to be entombed.

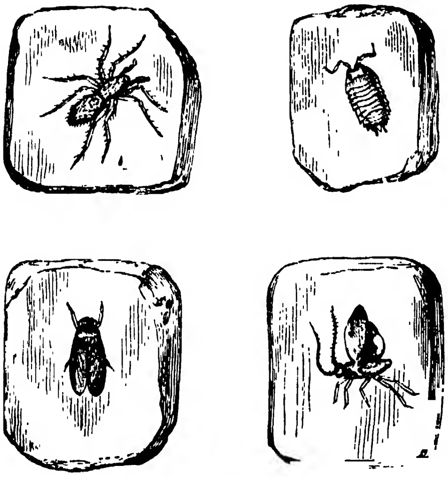
Fig. 2.—Animal Remains in Amber.

So plentiful are such organic remains in association with some of our modern resins, that animé is said to have obtained its name from this circumstance; *gum animé* being an animated gum. Incidentally it may be remarked that the term *gum* should be restricted to such bodies as are soluble in water, or are at least softened by it, while the term *resin* is reserved for those bodies which are not affected by water. Many natural exudations are mixtures of substances belonging to the two classes, and are therefore termed *gum-resins*. If the natural resin, as it flows from the tree, be mixed, not with gum, but with oil, the product is then known as a *balsam*.

It thus appears that resinous exudations are not necessarily definite chemical compounds, but are to be regarded, in most cases, as mixed bodies of variable composition. Such, too, is the case with amber. A careful chemical study of this material shows that, so far from being a simple resin, it contains two or three distinct kinds of resinous bodies, with a small proportion of certain other constituents, such as an acid called succinic acid.

One of these resins, however, is dominant, forming nearly nine-tenths of the amber, and this principal constituent has been isolated by Professor Dana as a distinct mineral species to which he has given the name of *succinite*. The amber itself cannot in strictness be regarded as a true species, inasmuch as it is a mixed body, and the scientific notion of a mineral-species carries with it the idea of homogeneity, or uniformity of composition. A mixture of minerals is, generally speaking, a *rock*, and not a *mineral species*.

Succinum, from which the specific term "succinite" is derived, was the Latin word for amber, and this alone is sufficient to show that even the Romans connected it with *succus*, the juice or sap or exudation of a tree. In fact, the occurrence of organic remains enveloped in amber was much too striking a fact to be overlooked by any one who had much to do with the material, while the significance of these remains was easily understood, even by unscientific observers. Pliny's account of the origin of amber is sufficiently accurate, and even the myths of the ancient poets are not altogether destitute of foundation. According to the Greek legend, amber was the petrified tears shed by the sisters of Phaeton, who were transformed into poplar-trees while bewailing their brother's death. The idea of a vegetable exudation evidently lies at the root of this legend.

Although several resins closely resembling amber are produced at the present day, it can hardly be said that any true amber is now in course of formation. The trees which yielded amber flourished during part of the Tertiary period, but have long since become extinct. The resinous substance which they produced became embedded in the earth, and in course of time gradually hardened: hence amber is best described as a *fossil resin.* Literally, the term "fossil" signifies something which is "dug up," the word being derived from the Latin verb *fodio*, "to dig." It was accordingly used by old writers to designate anything in the shape of a mineral substance, such as a piece of iron-ore; but in modern science the term has become conveniently restricted to denote the remains of some organism, dug out of the earth in a more or less mineralised condition, and generally representing some form of life which has become extinct. We speak, for example, of a fossil shell or a fossil coral, and in like manner we may refer to amber as a fossil resin. Such fossil resins, notwithstanding their organic origin, are admitted by courtesy into the mineral kingdom. They mark the meeting-point where the mineralogist and the botanist stand on common ground.

Mineralogists are acquainted with a large series of fossil resins, but amber is the only one of any commercial importance. Thus, during the excavations for Highgate Archway, there was found in the London clay a honey-yellow resin which has been called *Copalite*, *fossil copal*, or *Highgate resin.* It should be noted, however, that the term "fossil copal" has also been applied to the East African copal of the present day. For it is remarkable that much of this resin is found at depths of two or three feet beneath the surface, in districts near Zanzibar, where there is not at the present day a single copal-tree. So again the dammar resin, secreted by the kowrie-pine of New Zealand, is often found embedded in the ground. Such resins may perhaps be best termed *semi-fossil;* they differ essentially from amber and from other resins which are truly fossil, inasmuch as they are the products of trees now living, while the amber-trees are altogether extinct.

It was shown many years ago by Prof. Goeppert, of Breslau, that the amber-yielding trees must have been closely allied to the pine-trees of the present day. Pieces of wood, more or less altered, are occasionally found in such intimate association with the amber as to prove beyond doubt that they represent the very trees which yielded the fossil resin. The amber is found attached to the wood, or penetrating between the wood and the bark, or even between the rings of the stem which indicate annual growth. Fig. 3 shows the characteristic microscopic structure of the wood of the amber-tree. The principal tree has been termed by Goeppert *Pinites succinifer.* Other trees, however, no doubt contributed to the production of the resin. These amber-trees, as we learn by studying the associated remains, were accompanied by various species of oak, beech, birch, willow, camphor-trees, ferns, and other plants, mostly belonging, however, to species which are no longer living, and thus indicating the remote antiquity of the amber flora.

As to the animal remains which are enshrined in amber, these consist of just such creatures as we might expect to find creeping over the trunks of trees in the amber-forests. They are chiefly insects, spiders and small crustaceans, like wood-lice. It is not surprising that the spiders are especially numerous, inasmuch as these creatures would be found dwelling beneath the bark, or seated on the surface of the tree in such positions as to be readily overwhelmed by the flowing amber. A piece of a bird's feather has been recorded among the enclosures in amber, but it need hardly be said that specimens with small fish and even frogs, such as are occasionally offered for sale as remarkable curiosities, and are often figured in old works on natural history, are nothing but artificial productions. A suitable piece of amber is skilfully hollowed out into a cavity upon its under side, and into this cavity the organism is introduced; the orifice is then so neatly sealed up that the mode of insertion is not detected by an unpractised eye. It is worth noting that two pieces of amber may readily be united by smearing the surfaces with linseed-oil, and pressing them together while warm. In like manner, it is merely necessary to steep the amber in hot oil in order to soften it, so that it may be bent into almost any desired shape.

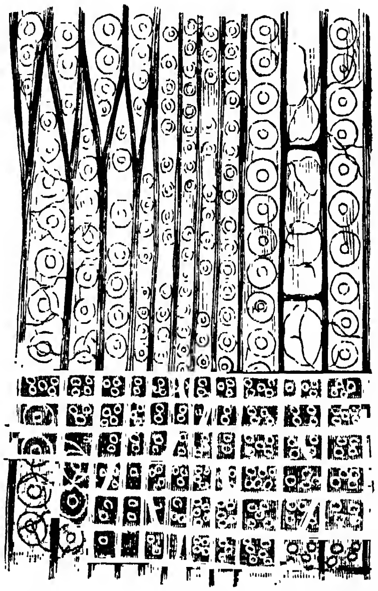

Fig. 3.—Microscopic Structure of the Wood of the Amber-tree (*Pinites succinifer*, Goeppert).

Looking at the geographical distribution of amber, it is clear that the extinct trees which yielded this resin must have flourished over a very wide area; while the vast quantity of amber which has for so many ages been obtained from the Baltic coast indicates the local luxuriance of the amber-pines. All over the wide plains of North Germany, amber may be found, in association with the lignites of the Tertiary series; but its principal locality is on the Prussian shores of the Baltic Sea, especially between Dantzig and Memel. There it is found in the "amber-earth," which is a loose clayey sandstone presenting, when fresh, a bluish colour, whence it is also termed "blue earth." The position of the principal amber-bearing bed, in relation to the overlying strata, is shown in Fig. 4. From the presence of sharks' teeth and other fossils in this blue earth, it is evident that the bed is of marine formation; while the dull and worn surface of the nodules of amber which it contains naturally leads to the supposition that the pieces of resin must have been rolled about on the shore or washed by the sea before they became embedded in this sandy deposit. The amber-beds belong to that division of the Tertiary series which is known as the Oligocene, or formerly as Miocene.

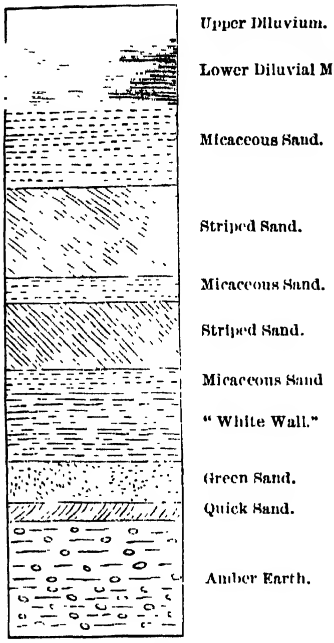

Fig. 4.—Geological Section of the Coast of Samland, near Gross Hubnicken, showing position of the Amber-earth.

The chief, if not the only, locality where amber is systematically worked by underground excavations, is at Palmnicken, in the peninsula of Samland, in Eastern Prussia. The earth from these mines is brought to the surface and carefully washed, when the pieces of amber are picked out and sorted for the market. At many points along the Pomeranian and Prussian shores of the Baltic, the amber is dug from the soil or picked from the cliffs. Sometimes the amber-gatherers explore the face of the cliffs in boats, and detach the amber by means of long poles. Others, again, merely collect the pieces which are cast ashore by the sea. The waves beating upon the cliffs, or tearing up the deep-seated beds, wash out the masses of amber. After a storm the detached nodules are heaved to the surface and floated to the shore. The amber-fishers, clad in leathern dresses, wade into the sea, and fish for the amber with nets, or pick it from among the stones on the margin of the shore, just beneath the sea-level, while, in deeper water, they obtain it by dredging or even by diving.

Most of the rough amber finds its way to Dantzig and Königsberg, where the trade is almost entirely in the hands of Jewish merchants. Some of the amber of commerce also comes from the western coast of Denmark, and the substance is likewise found on the south-eastern coast of Sweden. Occasionally pieces of amber are cast upon the eastern shores of our own island, especially near Aldborough, in Suffolk. It was also dug up, many years ago, in the old gravel-pits at Kensington. Some beautiful varieties of amber are found in Sicily, and important deposits are known in the neighbourhood of Bologna. It also occurs in the vicinity of the sulphur-mines of Cesena, in the Romagna, and has occasionally been found in Galicia, Silesia, Roumania, and elsewhere.

Much of the Italian amber is remarkable for its beautiful opalescence, or cloudy play of colour. The colour of amber is subject to considerable diversity, some varieties being of a pale primrose tint, or even quite white, while others present a deep reddish-brown colour, occasionally so dense as to appear nearly black. The variety most prized by the Orientals, who are great admirers of this material, is the straw-yellow amber, slightly clouded. Every Turk, however poor, strives to get an amber mouth-piece for his pipe, not only because the substance is beautiful in itself, but on account of the popular notion that it is incapable of transmitting infection—a point of some importance with people who hold it to be a mark of friendship to pass the pipe from mouth to mouth.

Amber has been a favourite material for ornamental purposes from a very early period. Homer, as the Rev. C. W. King has pointed out, makes no mention of any gem in his minute description of various jewels save the amber which decorated the gold necklace offered by the Phœnician trader to the Queen of Syra. It was one of the Seven Sages of Greece, Thales of Miletus, who discovered the remarkable property which amber possesses, when rubbed. of attracting light bodies.* This is the very oldest experiment recorded in the annals of electrical science. Indeed, the word "electricity" comes immediately from *electron*, the Greek name of amber. Possibly the word "electron" itself had reference to the characteristic yellow colour of amber, for it is notable that a pale yellow alloy of gold and silver was also called electron. As to our own modern word *amber*, it comes, like so many of our scientific words, from an Arab source.

By the Romans amber was so highly prized that Pliny tells us a small figure carved in this substance would fetch, in his day, more than a healthy living slave. Roman ladies at one period were in the habit of carrying a ball of amber in the hand, for the sake of the delicate balsamic odour which it emitted when warmed in this way. The German campaign of Germanicus led to an exact knowledge of the great amber-yielding locality on the Baltic. In the reign of Nero, who was a passionate admirer of this substance, a Roman knight was despatched to inquire into the amber trade, and thereupon the king of the amber-gatherers sent a present of 13,000 pounds to the emperor. The chief amber-yielding locality was known to the Romans as *Glesaria*, and the substance itself was termed by the old German tribes *gles*, or *glas*, a word with which our modern *glass* is closely connected.

It appears that when the Teutonic tribes settled in this country, they brought with them much amber, for beads and necklaces of this material are common in our Anglo-Saxon burial mounds. But there is indisputable evidence that amber was known and prized in this country in pre-historic times, probably ages before an Englishman ever set foot upon our shores.

If the reader will take the trouble to visit the Brighton Museum, he will there find, carefully treasured in one of the glass cases, the finest example of ancient amberwork ever found in this country. It is an amber cup (Fig. 5), holding a good half-pint, and showing by the concentric markings upon its surface that it must have been turned in the lathe. This unique specimen was found, many years ago, in a tumulus, or burial-mound, at Hove in Sussex. In the same barrow there had also been deposited a bronze dagger, a double-edged stone axe, and a whetstone. It is probable that the amber vessel was an imported article, for it is doubtful whether such an object could have been wrought in this country at so early a period. But whether the workmanship be native or not, it is almost certain that the raw material was of foreign origin; and it is a well-established fact that a widely-extended trade in amber was carried on at a very early period.

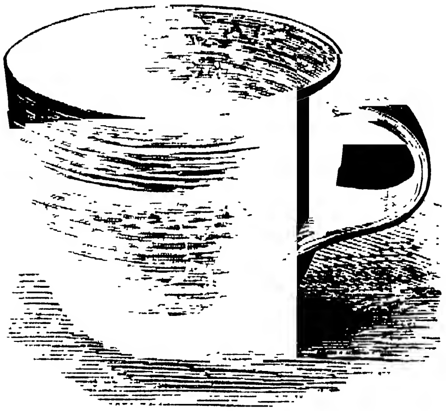

Fig. 5.—Ancient Amber Cup found in a Barrow at Hove, near Brighton.

Such enterprising people as the Phœnicians, the Etruscans, and the early Greeks, tempted by the great value of amber, pushed their way fearlessly across Europe, and came into commercial relations with the peoples of the North. By intercourse with the tribes dwelling on the Prussian and Danish coasts, amber was freely obtained, and carried to the south of Europe by these early pioneers of commerce. It was thus that amber was to be had at Olbia, on the Black Sea, or at Adria, at the head of the Adriatic, or at Massilia, in the south of Gaul; and from these ports it was readily distributed throughout the civilised world.

It is curious to reflect how so trivial a substance as the fossil resin of the Tertiary pine forests became in this way a means of opening up, at a very remote period, important lines of commerce between the north and the south of Europe, and by thus bringing distant peoples into relation with each other, assisted in dispersing a knowledge of the arts of life over a vast area. A piece of amber, in short, became a powerful factor in the early history of European civilisation.

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* "How Electricity is Produced:" "Science for All," Vol. III., p. 51.

LIFE ON THE SURFACE OF THE OCEAN.

By H. N. Moseley, M.A., F.R.S.,

Linacre Professor of Anatomy in the University of Oxford, late Naturalist on board H.M.S. "Challenger."

ALL of us are more or less familiar with the abundance of the living things which inhabit the sea coast, and with the variety of their forms. There are few indeed who have not gazed with wonder into a rock-pool at low tide and admired the brilliant clusters of sea anemones, the bright red star-fish, the darting prawns, crawling or swimming crabs, and the little fish sheltering under the weed. At all events, if such things have not become well known to us in their natural abodes, we have daily opportunities of studying their habits and appearance at leisure in our aquariums. But it is only the inhabitants of the shores with which we thus become acquainted, and we might be apt to suppose that such animals fairly represented the fauna of the ocean generally—that the main mass of living things by which the ocean is inhabited is of similar habit, clinging to the shores or the bottom, and adapted in structure for such existence. Such, however, is not the case; the surface water of the oceans, which cover in area nearly three-fourths (seven-elevenths) of the surface of the globe, teem with life, being crowded almost everywhere with peculiar vegetable and animal forms, which are specially modified to lead a free floating or actively swimming existence on the high seas, and which in actual numbers of individuals probably far surpass all other living things found on the earth, whether at the sea bottoms or on the land surfaces. These peculiar ocean-living plants and animals are technically termed pelagic (Greek, *Pelagos*, ocean), or oceanic, and constitute the pelagic flora and fauna. With pelagic plants and animals those who stay at home or merely make short voyages near the coasts of Great Britain have little opportunity of becoming acquainted. Now and then, after stormy weather, some few of these animals are cast up on the shores, and there may be found there such objects as the blue shells of the beautiful pelagic snail *Ianthina* (Fig. 1), or the floating bladders of the Portuguese man-of-war, which sometimes explode under the feet of the walker on the sands. When washed ashore, however, the pelagic animals become at once mere wrecks. Their bodies are excessively perishable, and they collapse and shrivel up immediately they cease to be supported by the surrounding water.

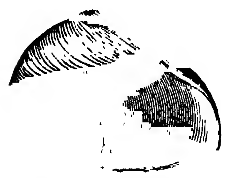

Fig. 1.—Ianthina.

There are nevertheless some places at which the majority of pelagic animals, owing to peculiar circumstances, can be caught near shore, in abundance, and examined at leisure by the naturalist on *terra firma*. Foremost amongst such localities stand oceanic islands: such, for example, as Madeira, where most important investigations into the structure and life-history of very many such animals have been made by Prof. Haeckel of Jena, and which is much resorted to by other naturalists for the same purpose. Oceanic islands stand, of course, in the midst of the area occupied by the pelagic fauna. Other productive localities occur in narrow straits, where there are constant currents which carry the pelagic animals through them from the open seas. The Straits of Messina thus afford a rich harvest to the naturalist, and similarly some of the sea passages in the Philippine Islands were found by us during the cruise of H.M.S. *Challenger* to fill our nets with pelagic prey as the tidal current ebbed and flowed through them.

It is, however, reserved for those who go on long voyages and spend months or years upon the ocean to realise fully the vast abundance of pelagic life. It is truly astonishing, during a sail of two or three days on end, to see, whenever one glances at the sea surface, the whole area thickly set with small masses of jelly, which, as a naturalist, one knows to be the compound organisms called Radiolarians. The whole surface of the sea, far and wide, in some regions, appears full of these organisms drifting about, in some places scattered, but nowhere more than a foot apart, and in other places clustered together densely in long stream-like bands.

To catch the pelagic animals and plants a simple net, called a tow-net, is used. It is a conical-shaped bag net of fine gauze or bunting, stretched at the mouth on a hoop of iron wire: in fact, very like a butterfly-net without a handle. The net is towed slowly through the water, and gathers all that comes in its way. It is then drawn in and turned inside out, and the muslin bottom is washed in a globe full of fresh sea water. It is a wondrous sight indeed to see, after a good catch, the immense variety of living things which, thus being washed off the inside of the net, are set free swimming in the bowl, some minute, scarcely visible, some large, some darting violently about, others leisurely swimming, others, again, floating passively in the eddies in the bowl. If it be dark some gleam brightly with phosphorescent light. We will consider first some of the pelagic plants, and then have a look at some of the animals.

The sea surface in many regions is crowded with vegetable life. Everywhere in the ocean amongst the contents of the tow-net are to be found living *diatoms*, lowly organised plants, allied to ordinary sea-weeds, but consisting mostly of single microscopical cells. These cells have each a coating of flinty matter, which is marked all over with beautiful symmetrical patterns. Diatoms are hence well known to all who possess a microscope, being the most beautiful objects to be observed by means of this instrument. They inhabit fresh waters as well as salt, and the shores and sea bottoms in shallow water as well as the open oceans. They are especially numerous on the sea surface in the Arctic and Antarctic regions, where they are so abundant as to tint the water and colour the ice on to which they are washed up of an olive-yellow hue.*

In tropical waters another lowly organised plant, allied to the diatoms, but without any hard flinty coating to its cells, abounds. When it is present in quantity the water looks as if it were full of minute fragments of chopped hay. The minute plants causing this appearance, when examined with the microscope, are found to consist of brown faggots of minute threads, each thread made up of a row of little cells. In some species the threads are not joined together in faggots, but massed in little rounded tufts, with the threads all pointing outwards. These plants belong to the genus *Trichodesmium* (hair bundles). When tracts of the sea, lighted up by the sunlight, are passed through which are full of this plant, the water, when looked down into from the deck of a ship, appears as if full of glittering particles of mica, so strongly is the light reflected from the minute bundles of which the plant consists. In some tropical seas the whole surface of the water, far and wide for hundreds of miles, is discoloured brown with this plant, and a strong smell arises from the water, like that from a weedy pond. So abundant is *Trichodesmium* in some seas, that one of the explanations of the name of the Red Sea is that the term was derived from the discoloration of the water by vast quantities of one species of it. (Vol. III., p. 23, Figs. 3–7.)

But besides these microscopic plants there are other much larger ones which are pelagic.

The well-known Sargasso Sea is filled with the large tufts of a sea-weed not very unlike the common yellow-brown slimy weed, covered with little bladders (*Fucus vesiculosus*), which grows so abundantly on the shores of Great Britain. The weed of the Sargasso Sea, *Sargassum bacciferum* (berry-bearing), is so named from its bearing all over little spherical bladders, which act as floats and support it in the water. On many tropical coasts this Gulf-weed grows attached to rocks, but in the open ocean it lives, grows, and multiplies, floating freely hither and thither with the current or wind. When thus living free it is of a most brilliant yellow colour, which contrasts most beautifully with the deep blue of the open ocean. Other sea-weeds grow floating freely in other parts of the world.

Were it not for the abundance of vegetable life in the surface waters of the ocean, there would be very little animal life there, since all animal life is eventually dependent on that of plants.

Let us now consider some of the pelagic animals. Nearly all the common animals which we spoke of as familiar in rock-pools on our coasts have representatives which live free, floating far away from land; but these representatives are all modified in some way or other, to suit their peculiar pelagic life. Thus, there are even pelagic sea anemones.

The sea anemones of the coast, it is well known, cling to the rocks by means of a broad, flat, adhesive disc; we have all of us pulled them off their supports to put them in aquariums, and know what the disc is like. In the pelagic anemones the edges of this disc are brought together, and the disc itself is formed into an air-chamber, by means of which the anemones float base uppermost at the surface. On the voyage of the *Challenger* we found numbers of such anemones floating on the surface, near the Virgin Islands, West Indies.

There are similarly pelagic worms. They swim with great rapidity, and are like nearly all other pelagic animals, perfectly transparent and glass-like in appearance. By being so transparent the pelagic animals are protected from enemies of all kinds, from oceanic birds, fish, and turtles. It is almost impossible to see most of them in the water when peering into it from a small boat: they are only descried when turned out of the net into the bowl; even then the pelagic worms are difficult enough to see. No doubt pelagic animals have become thus transparent through the action of natural selection. Some of them cannot manage to do without some part of their organs being opaque; in these cases they have such organs most usually coloured brown, to resemble the floating sea-weed, and so escape observation. Those that are not coloured brown are mostly of a beautiful blue colour, to match the colour of the sea, and thus hide themselves.

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* "The Colour of the Sea:" "Science for All," Vol. III., pp. 17-25.

Many of the pelagic animals are like the floating anemones and worms, animals which have apparently sprung in comparatively recent times from ancestors which lived in the waters of the shores or on dry land, and which have become modified in more or less unimportant particulars of their structure to adapt them to pelagic existence. Many other inhabitants of the ocean surfaces, on the other hand, have no immediate relatives inhabiting the coast waters. The groups which they compose are pelagic only, and have evidently lived for vast periods of time an oceanic existence. Such a group are the Pteropods, for example. These are small mollusca, distantly allied to the common snail, more nearly to the cuttle-fish, but forming a group quite apart from the rest of the Mollusca. They are most beautiful animals—the butterflies of the ocean (Fig. 2). They are all small, mostly under a half or a quarter of an inch in length; they have a pair of wing-like fins attached to their heads, by means of which they swim with great rapidity, flapping the fins as a butterfly does its wings. It is astonishing to see one dart round a glass globe when set free from the towing-net. Most of them have their bodies enclosed in beautiful transparent shells, from which the wings are protruded for swimming, and into which they are drawn back when danger threatens. These animals in the Arctic seas are so abundant as to form the food of whalebone whales.*

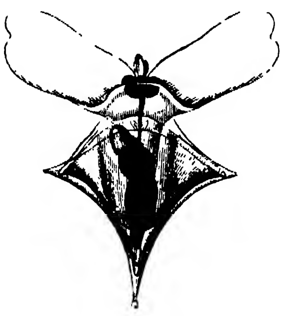

Fig. 2.—Cleodora.

Another group of animals which is entirely pelagic is the *Siphonophora*. These are compound colonies, made up, as in the case of coral trees, to which they are allied, of numerous animals joined together in one mass for mutual benefit. Some members of the colony act as swimming organs, and propel the whole mass through the water; others catch the food and deliver it again to another set, whose sole function is to digest it and nourish themselves and the whole colony; other members, again, produce and rear the young, being the nurses of the colony, whilst others, again, protect the colony from enemies by means of batteries of stinging organs. There is a great variety of kinds of these curious compound colonies of animals, the *Siphonophora*. The various animals composing each colony are joined intimately together in a single continuous jelly-like mass. In some the swimming members of the colonies are very active indeed, and by their means each colony darts about with great rapidity through the water.

Some of the colonies are supported at the surface of the water by means of a large float, beneath which hang the various members composing them. The Portuguese Man-of-War (*Physalia utriculus*) is one of these. In the accompanying figure of this animal (Fig. 3) is seen the bladder like float above, whilst beneath are a series of flask-shaped objects. These are the larger animals of the colony, which devour the food and digest it. At the tips of the flasks are situated the mouths. Above the bases of the flasks, close under the float, is seen a fringe hanging down. This is composed of numerous very simple animals, which catch the colony's food. From some of them depend long threads, which threads are full of the stinging cells already referred to, and the effects of which many bathers know too well.

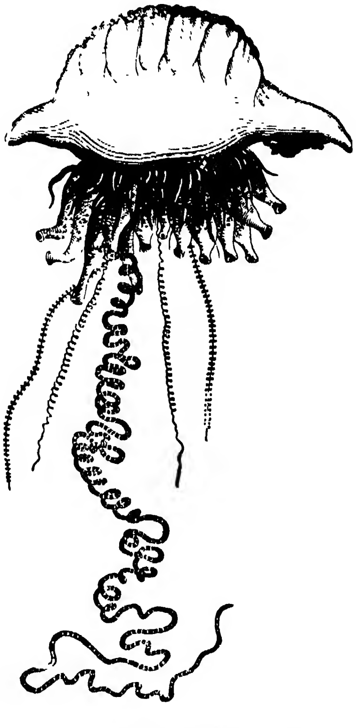

Fig. 3.—Portuguese Man-of-War

The Gulf-weed of the Sargasso Sea is inhabited by a fauna peculiar to itself, all the animals composing which are specially adapted to their life amongst it. They are all coloured, for purposes of protection and concealment, exactly like the weed itself. The peculiar shrimps and prawns which swarm in the weed are of exactly the same shade of yellow as it, and they have irregular glistening white markings on their backs, which exactly match white shelly incrustations formed abundantly on the weed by microscopic compound animals. Some of the animals resemble the older browner pieces of weed, and nestle amongst it; others, the younger and yellower pieces. There is a small, stumpy-looking fish which lives amongst the weed, and clings on to it by means of curious long arm-like fore-fins. It makes a nest of the weed, binding together a globular mass of it as big as a Dutch cheese by means of long sticky gelatinous strings, which it forms for the purpose, and in the centre of the nest it deposits its eggs. Such nests are common objects amongst the weed. This little fish, of which the accompanying woodcut is an illustration, is called *Antennarius* (Fig. 4). It is covered all over with curious projecting outgrowths, which are branched at the ends, and which resemble very much small tips of the branches of sea-weed. The fish itself is of the same colour as the weed, mottled with white spots, and when in its singular fashion it clings to a branch of weed in the water with its long fore-fins, much as a frog holds on to weed in a pond with its arms, it is very difficult indeed to detect it, so closely does it resemble the object on which it rests. This fish is adapted only to live amongst the weed. It is a very feeble swimmer, and, if it gets washed away from its home, drifts before the current. It is sometimes thus found on the shores of Great Britain, though a tropical fish, having been carried to our coasts by the Gulf Stream. There are worms and seaslugs also inhabitants of the Gulf-weed, and coloured like it, and other animals which cannot here be described.

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* "Science for All," Vol. III., p. 21.

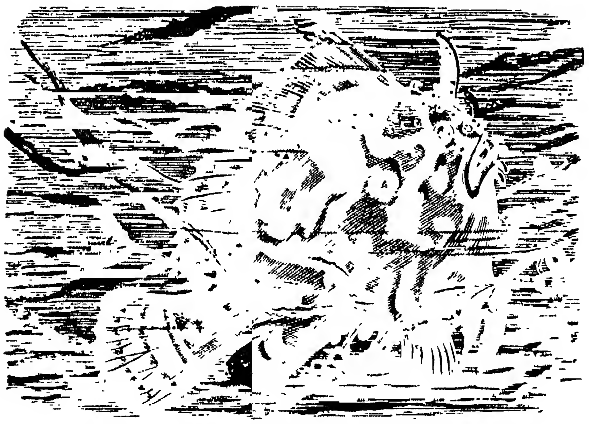


Fig. 4.—*Antennarius marmoratus*, a Nest-building Fish.

The fish of the open ocean are peculiar, and mostly different from those which inhabit the coasts of continents. Amongst pelagic fish, the best known, no doubt, are the flying-fish (Fig. 5). There are two very different sets of flying-fish; there are the flying-fish proper, with small heads and herring-like appearance, allied to the long-snouted garfish of our southern coasts; and the very different broad-headed flying gurnets. In both the fore or breast-fins have become developed into organs of flight; but the flying gurnets and the other flying-fish are not at all related to one another in other details of their structure, and no doubt they have developed their powers of flight quite independently by the aid of natural selection. Most probably they gradually arrived at powers of flight from being constantly chased by large predatory fish, such as albacores. I have seen a shoal of little garfish, when chased by an albacore, skipping along on the surface of the water in front of their enemy, just keeping themselves out of the water and of his reach by violent efforts of their fins and tails. It is easy to conceive that those who manage to keep above water longest would survive, and that in the course of generations this would tell upon the race and gradually give rise to powers of short flight. The flying-fish allied to the garfish belong to the genus *Exocœtus*, of which there are many species. It is these which are most commonly seen by voyagers starting out of the water in flocks on either side of a vessel as they are scared by her passage through the water. They spring from the waves by the help of a violent lash of the tail, and, with their wings set out stiff, skim over the surface of the water, the wings glistening in the sun, for as much as eighty or ninety yards sometimes. Then, their impulse being exhausted, they drop with a flop into the water. It is a much-debated question whether any flying-fish flap their wings at all whilst in the air. As far as I have seen, the Exocœti never do. Their wings quiver in the wind as they fly, but remain fixed at their bases. Some of the flying gurnets do, however, I am sure, flutter their

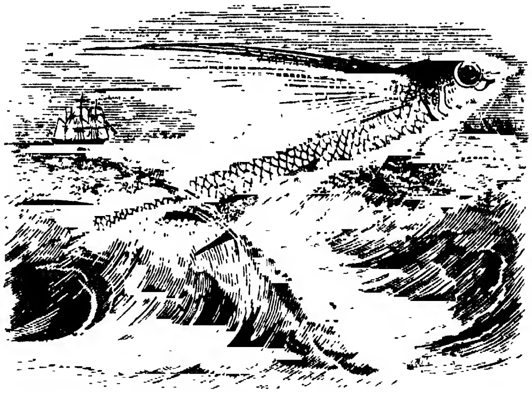
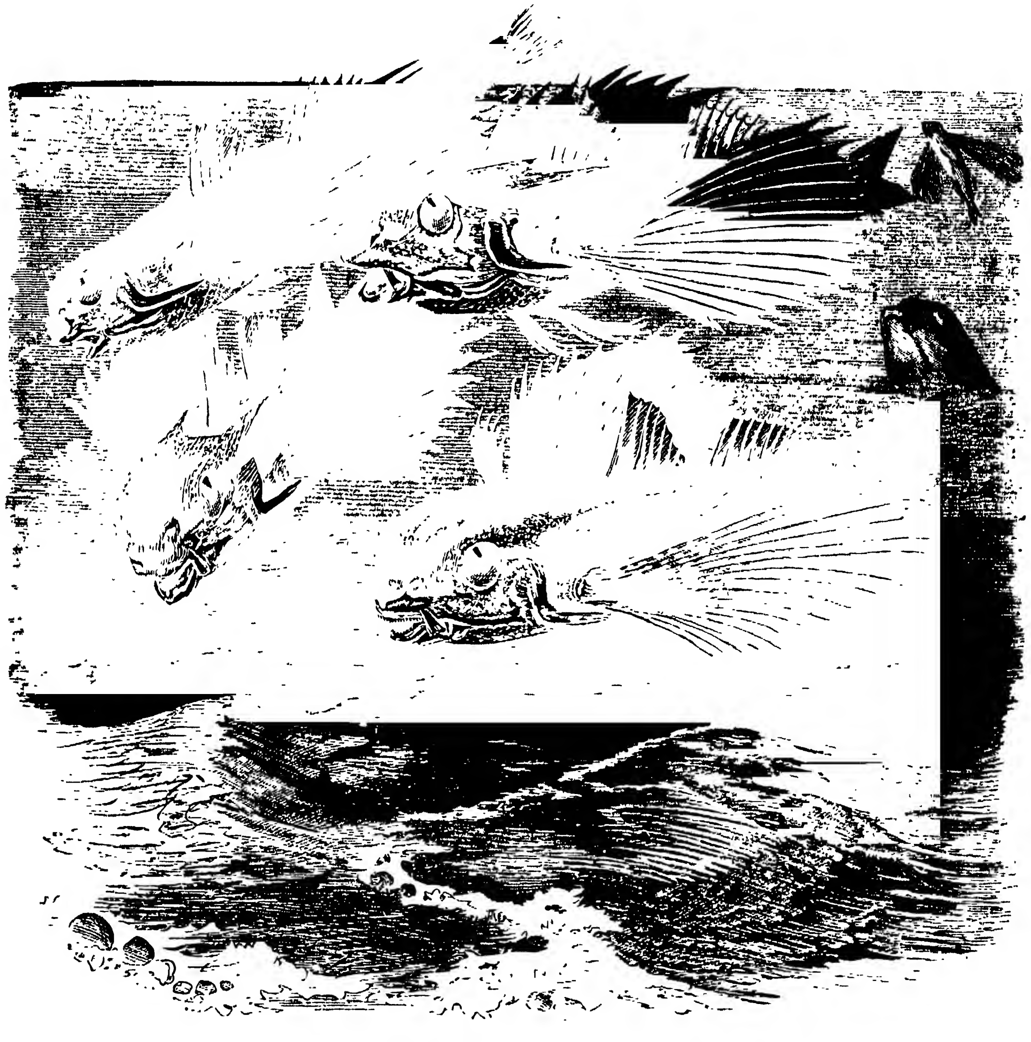


Fig. 5.—*Exocœtus volitans*, or Flying-fish.

wings. I once chased a beautiful little flying gurnet, which inhabits the Gulf-weed. As I kept coming up with it in a small boat, it rose in front of the bows and seemed to buzz its wings rapidly, somewhat like some grasshoppers do as they fall gradually to the ground after a short leap and struggle into the air. The flying gurnets (Fig. 6) are closely like ordinary gurnets, excepting in the wing-like form of their breast-fins. They belong to the genus *Dactylopterus* (finger-wings). The little species living in the Gulf-weed has its wings brilliantly coloured, like those of a butterfly. A large species is very abundant round the island of Ascension, and I have stood in the bows of a steam-pinnace, when coasting along the island, and tried to shoot them on the wing as they rose right and left like snipe before the vessel. I hooked one once when fishing with a fly-rod for small fish at the Cape Verde Islands. Playing it, was, however, a very different matter from playing a trout. It took a fly round me out of the water, dropped in, and was out again in an instant, and soon shook itself loose of the hook.



g. 6.—Dactylopterus, or Flying Gurnets.

The other pelagic fish most commonly met with on voyages are the albacore and the bonito, both allied to the mackerel and the tunny, running up to twenty or thirty pounds in weight or more. These are sometimes caught by means of a spinning bait, towed from the dolphin-striker of a vessel. Then there is the so-called dolphin (*Coryphæna*), a fine large fish, beautifully coloured brilliant blue and yellow, a truly magnificent sight as seen from the deck of a becalmed vessel, swimming leisurely round her. Almost the only other fish very commonly met with in the open ocean by the voyager is the pilot-fish (*Naucrates ductor*), which swims just at the bows, nearly touching the ship's side, for days and days, probably thinking it is piloting a very large shark, and hungrily wondering when the monster is going to feed and leave it some crumbs. There are other pelagic fish which are very small, and, like so many other pelagic animals, have their bodies perfectly transparent. These are often found in the towing-net. Some are the young of fish which, when mature, live on the sea bottom, but which in their early days lead a pelagic existence.

The largest pelagic animals are, of course, the whales. Their ancestors, allied to the seals, no doubt, in ages past, resorted to the shores at the breeding season. Even now many of the whales perform regular annual migrations. But of these and the porpoises we cannot speak here. They are instances of mammals which have adapted themselves to a pelagic existence. Some representatives of almost all land animals have done likewise. There are the pelagic birds, the various species of albatrosses and petrels so well known to all voyagers in the southern seas or Pacific Ocean; and there are even pelagic insects. A small insect, allied to the long-legged insects (*Gerrys*) which are so commonly to be seen resting on the surfaces of ponds and ditches in England, moving along by a series of jerks, and casting curious shadows on the bottoms of shallows when the sun is overhead, is commonly to be found in the towing-net when used almost anywhere in the open warmer Atlantic or Pacific Oceans. The insect is named *Halobates*, or the "sea-walker." It is black coloured, with a globular-shaped body and long legs (Fig. 7). It is astonishing that it should be able to outlive the storms of the ocean.

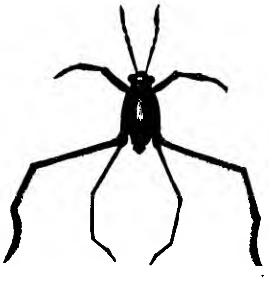


Fig. 7.- Halobates.

But the most interesting of the pelagic animals are, after all, those which are microscopic. The waters swarm almost everywhere with minute crustacea of most various forms. Some are red, some blue, some endowed with the most brilliant conceivable iridescent colours of all hues. Often they are met with in such vast quantities that they colour the water, and sometimes render it thick, like pea-soup. Some of them have most enormous eyes, so large in proportion to their bodies that the animals appear as if they were nearly all eye. One has a large projection from the under part of its body, the only function of which is to contain the back parts of the huge eyes, which stretch through the entire body and yet cannot find room enough.

Of very great importance amongst the surface animals are the pelagic Rhizopods. Rhizopods are extremely simple animals, the bodies of which are composed of a jelly-like substance devoid of organs of any kind. They can contract their body, and can also push out small portions of it in any direction from any part of its surface, and by means of these lay hold of food, which is passed into the jelly anywhere as may happen, and, lying embedded in it, becomes digested. Some of these Rhizopods are provided with most delicate and beautiful calcareous shells, and some of these forms live at the sea bottom, whilst others are pelagic. One of the most remarkable of the pelagic forms is *Globigerina*. The pelagic globigerinæ have a shell composed of several globular chambers, which are covered all over with most delicate spines. These spines are very long, and form a regular forest over the shell, and by increasing vastly the area of resistance of the animal, they tend to keep it at the surface of the water. The dead shells of the globigerinæ * and their allies drop to the bottom of the deep sea, and there assist largely in the formation of the globigerina mud, the modern representative of chalk, so well known from the writings of Dr. Carpenter, Sir Wyville Thomson, and other explorers of the deep sea.

The habits of pelagic animals are little known. Many of them rise to the very surface of the sea at night, and sink to some depth during the day. Others, again, rise in the daytime and sink at night. It is not known with any certainty to what depth the pelagic animals range: the question is of the greatest interest. The animals are to be found abundantly in tow-nets which have been let down to a depth of a hundred fathoms or more; but when an open net has been towed through the water from any great depth, the animals found in it at the surface may have come from any intermediate depth, and been caught as the net was coming up. However, from a series of experiments made on board the *Challenger*, it seems certain that some of the animals extend to a depth of more than a hundred fathoms. Very possibly there is a wide expanse of water between the bottom of the deep sea and the first two or three hundred fathoms of its surface which is nearly or quite devoid of life of any kind. We may hope soon to know something certain about the range in depth of oceanic animals, for Mr. Alexander Agassiz, the American naturalist, is engaged in experimenting with a net which can be let down to any depth with its mouth closed, then opened and towed along at that depth, and then again closed before being brought to the surface. Thus anything found in such a net will certainly belong to the depth to which the net was lowered.* Certain it is that at a depth of one hundred fathoms there is no sunlight at all, so that the animals living there or at greater depths must be like those on the deep sea bottom, always in the dark, excepting as regards the phosphorescent light given out by themselves or other animals.

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* "The Bottom of the Sea," Vol. III., pp. 79, 80, Figs. 1, 2.

The wonders and beauty of the phosphorescence exhibited by the pelagic animals has formed the theme of many writers. Many different pelagic animals are phosphorescent, and the kind of light emitted and the manner of its appearance vary, according to the nature of the animal causing it. Sometimes the sea, far and wide, as far as the eye can see, is lighted up with sheets of a curious weird-looking light, and wherever the water breaks a little on the surface before the breeze the white foam is brilliantly illuminated. This kind of phosphorescence is due to a minute globular gelatinous animal named *Noctiluca* (p. 47). Such displays as above described are comparatively rare, and in order that they should occur, the animals must be present in very great abundance, the sky must be cloudy, and there must be a breeze to agitate the animals, and thus cause them to emit their light more brilliantly. We saw only one such scene during the whole of the *Challenger's* voyage of three years and a half. It occurred in the equatorial Atlantic Ocean, between the Cape Verde Islands and St. Paul's Rocks. So bright was the light that the lower sails of the ship were seen to be distinctly lighted up by the light given off from the broken water thrown up by the hull of the vessel.

At other times the water, where disturbed, is seen to be full of small luminous scintillating specks. This is the commonest form of phosphorescence in the open sea, and is due to various small animals, principally crustacea, which give out their light by flashes. Some small crustacea are luminous apparently only because they feed on the luminous matter of other animals.

The most beautiful kind of phosphorescence is that produced by the curious ascidian colony *Pyrosoma* (fire-body). These compound colonies are transparent masses of a cylindrical form hollowed out inside into a tubular cavity, open at one end. They are made up of hundreds or thousands of similar animals, all packed in a common jelly, one over the other, in the wall of the tube. Each animal can take in water by an opening situated on the outer surface of the cylinder, and eject it through another opening into the tubular cavity inside it. The animals breathe and feed by thus drawing a stream of water through their bodies, and as the water sent through by all the members of the colony passes out of the opening at the end of the cylinder, the cylinder or whole colony is moved slowly through the water, away from the direction of the opening. A Pyrosoma colony, when stimulated by a touch or shake or swirl of the water, gives out a bright globe of bluish light, which lasts for several seconds as the animal drifts past the ship several feet beneath the surface of the water, and then goes out suddenly.

Pyrosomas are commonly found of about six or eight inches in length. One was caught during the *Challenger* expedition, in the deep-sea trawl, which was a very giant. It was like a great sac, with its walls of jelly an inch in thickness. It was four feet in length, and ten inches in diameter. When a Pyrosoma is stimulated by having the surface touched, the phosphorescent light breaks out brightly at the spot irritated. I wrote my name with my finger on the giant as it lay in a tub on the deck, and it came out in a few seconds in letters of fire.

Most of the various forms of pelagic animals have an almost world-wide range, so far as the temperature of the water will allow. In being thus widely distributed they resemble the deep-sea animals, which are nearly alike all over the world, from the coast of Portugal to Japan. Many of the species of pelagic animals occurring in the Pacific are slightly different from those occurring in the Atlantic, though closely allied to them. But it is remarkable how closely large catches turned out of the towing-net in either ocean resemble one another. The general components of the mass caught in both places are virtually the same. It would be impossible, were such not the case, in a paper such as the present, to give any adequate conception at all of the *fauna* and *flora* of so vast an area as the ocean surface, that is to say, of three-quarters of the earth's surface; but as already stated, it is almost impossible, without the experience gained on a long voyage, to realise the abundance and variety of pelagic life.

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* Since the above was written, Mr. Agassiz has published an account of his experiment, which appears to show that pelagic life does not extend to a greater depth than 100 fathoms.

A GNAT.

By Arthur Hammond, F.L.S.

PERHAPS few members of the insect tribes are better fitted to attract our attention and to stimulate a thirst for knowledge than that which forms the title of this paper. Their vast numbers in all three stages of their existence almost force them upon our notice, independently of other and well-known means which they possess of making their presence felt. Common as they are, though, it is perhaps pardonable to express a doubt whether they are after all so familiar as to render a definition of them entirely superfluous. It is not every minute insect which dances in clouds on a summer evening that is entitled to the term. One of these, distinguished for its feathery antennæ, is frequently mistaken for a gnat. Let us look at this fellow for a moment, that by seeing what a gnat is not, we may the more accurately know what a gnat is. It is called *Chironomus plumosus*, and is represented here in Fig. 1. In Fig. 2 is shown a magnified drawing of the head, from which it will be seen that it is furnished with a short proboscis, which is terminated by two large fleshy lips. If this be compared under a lens with the head of a larger and well-known insect—the crane fly or daddy long-legs—we shall see that the structure of the mouth in the two insects is essentially similar: in fact, that Chironomus is a daddy long-legs writ small, with the addition of the feathery (plumose, as it is called) antennæ; and neither of these insects has the least power of piercing or biting the skin, the fleshy lobes with which the mouth is armed being adapted for suction only, as is the case with those of the house fly, already described. Chironomus, too, differs from the gnat in being produced from a totally different larva—the blood worm, or figure-of-eight worm, a creature sufficiently known by its name.

Let us now look at one of the real culprits, the nightly disturbers of our rest. Here is one taken in the very act, and even a slight examination with a lens reveals the fact that, instead of a short fleshy proboscis, the head is furnished with a long, slender, tubular organ (Fig. 4), of which more anon. It is the presence or absence of this elongated proboscis that decides the question of gnat or no gnat.

Réaumur tells us that the eggs of the gnat are laid in a small boat-shaped mass, which floats upon the surface of the water. The eggs are of an oval form, with a kind of knot at one end, and are arranged side by side, closely packed together (Figs. 5, 6). The larvæ which proceed from them may be seen in most stagnant waters during spring and summer, and are familiar even to children. They are in the habit of floating head downwards, suspended by the tail—if we may be pardoned the expression—from the surface of the water for the purpose of respiration, whence, if alarmed, they suddenly dive by a succession of quick jerks to the bottom. We must carefully examine this little creature, for we shall find it repay all our attention. It will be seen from Fig. 7 that the body consists of thirteen segments, one for the head, three for the thorax, and nine for the abdomen. Each segment, especially those of the thorax, is provided with a tuft of fine hairs, and it will be specially noticed that the thoracic segments are very much broader than the rest of the body, to allow room for the formation within them of the wings and legs of the future insect. The twelfth segment has a long respiratory appendage, into which the main tracheæ run, and which it exposes to the air while suspended in the attitude before described. Commencing our description with the antennæ, we shall find them to consist of a single joint (Fig. 8), ornamented at about half its length with a tuft of fine hairs. Two black patches on either side of the head represent the eyes. Both these organs of the senses are marked by a want of finish, as compared with those of the perfect insect: in the former it is evidenced by the absence of joints, and in the latter by the absence of facets, the eyes appearing to be little else than masses of pigment beneath the skin; but we shall not be surprised at this when we recollect that the business of the larva is chiefly to feed and grow, and so lay up a store of nutriment in its body, in anticipation of its entry into the winged state, where all the senses are brought to perfection. In conformity with this, we shall find the mouth organs which minister to this purpose very elaborately formed. The most prominent of these are the mandibles (Figs. 8, 9), which, instead of being adapted for cutting and tearing, as in the cockroach, or absent, as in the house fly, are now found as brushes of hairs (ciliated, they are called—from the Latin *cilium*, an eyelash), which, when employed in the prehension of food, perform a succession of rapid movements, being alternately thrust out and withdrawn from the mouth in a manner difficult to describe, but which, more than anything else, may be likened to the sudden appearance and disappearance of a chimney-sweep's brush from the top of a chimney, the hairs spreading apart and around on every side. If it be asked, How are we to know that these organs are the same as those so differently formed in the cockroach? the reply is, that they are the most superior of the paired organs, being found just below and on each side of the small triangular ciliated tuft which forms the labrum. The manner in which the curious movements of the mandibles are brought about is believed by the writer of this paper to be as follows:—The hairs, some of which are toothed (Figs. 9, 10) so as to resemble very minute combs, are attached to the outer surface of a portion of the integument capable of inflation, so as to assume a more or less convex form. When the mandibles are at rest this surface is nearly or quite flat, and the brushes of hairs rise perpendicularly from it, as in Fig. 12. But when brought into action it is blown out, as in Fig. 11, the hairs and combs being spread out in consequence, as therein indicated. That this is the case is further evidenced by the fact that in a recently killed larva movements exactly similar may be produced by gentle pressure with the point of a needle upon the surface of the head or even of the thorax, when the brushes will be seen to spread out by the transmitted pressure of the fluid contents of the body, precisely as they did during life, and to close up again after that pressure is removed. Probably during the alternate opening and closing of these brushes many small animalcules are entrapped between the hairs and the combs, and are thus brought within reach of the other mouth organs. On the under surface of the head, just below the mandibles, are the maxillæ, shown in Fig. 13, and below these again the labial palpi, shown in Fig. 14. Both these pairs of organs partake of the ciliated character of the mandibles, though to a less extent.

The thorax is that swollen portion of the body immediately following the head, consisting, as usual, of three segments. The chief point of interest connected with it is the facility with which, in the full-grown larva, the wings and legs of the pupa can be seen through its transparent skin. It will be remembered that in the house fly the skin of the larva dies, and forms a hard, barrel-shaped, protective case around the soft and motionless pupa. It is different, however, with the gnat, which sheds its larval skin, and numbers of these shed skins may be found in any pond in which the larvæ reside. Previous to this, the wings and legs of the pupa are fully formed within it, and may be seen through the skin (Figs. 16, 17) coiled up and packed together in the closest possible compass. It must not be expected that they should present anything like the finished shape and proportions of those of the perfect insect. They are, and continue to be during the whole of the pupa state, mere cases, within which the future limbs of the latter are gradually formed, and may with propriety be spoken of as such.

The last, or thirteenth, segment of the body is remarkable for the curious fan of hairs with which it is furnished. These arise from the centre of a gridiron-shaped organ, shown in Fig. 15. It is probably the means whereby the larva executes its swift descent to the bottom when alarmed.

The pupa of the gnat is no less remarkable than its larva. The limbs which were so closely swathed within the larva skin now assume a more bulky arrangement, and form a large oval mass, enclosing a quantity of air within their folds, the result of which is that the thorax of the insect is brought above the surface of the water; and the tail, or more correctly speaking, the abdomen, hangs down. In this position the insect breathes by means of two prominent organs on the prothorax communicating with the main tracheæ, the respiratory appendage of the abdomen being supplanted by a pair of swimming leaves. Unlike the helpless pupa of the house fly, it is capable of considerable exertion, and if touched wriggles actively down several inches below the surface, to which, however, it is soon brought again by the buoyancy of the thorax, and resumes its former position. Fig. 19 represents the insect in this condition. It should be noticed that the new respiratory organs on the prothorax represent the upper pair of appendages of that segment, as was stated in my paper on the house fly; and, further, that the cases of the halteres correspond both in position on the segment to which they belong—viz., the metathorax—and also in general outline, with the true wing-cases on the mesothorax, and that, notwithstanding the dissimilarity of the organs which are eventually formed within them, showing in the most striking manner that the halteres of the perfect insect are, as before stated, modified wings, the superior appendages of the metathorax. Every limb of the future insect may be detected in course of formation within its own proper limb-case, including the antennæ and the mouth organs, which, be it remembered, are but modified limbs.* Some of these are shown in Figs. 21, 22, 23, and 24. The final transformation of the gnat, by which it exchanges the pupa for the winged condition, has been described by Réaumur, a copy of whose figure will be found at Fig. 25, where the insect is seen making use of the cast-off skin of the pupa as a raft, upon which it floats while drying its wings and preparing for its final leap into the air.

The gnat is a dipterous or two-winged insect, similar in this respect to the house fly; but we shall soon find on examination that there are very important differences, among which must first be noticed the difference in the antennæ, which consist of a considerable number of joints arranged one after the other successively, and not, as in the fly, having the last three springing from near the base of an enormously enlarged third joint. This at once places the insect amongst the Nemocera, or thread-horned section of the Diptera, to which also the daddy long-legs, or crane fly, and *Chironomus plumosus* belong. From these, however, as before stated, it differs in the structure of the mouth, and in virtue of this it belongs to the family Culicidæ, or true gnats, as distinguished from the Tipulidæ, which includes the insects just mentioned. Of this family three genera and twenty-four species are found in Great Britain, the genera being distinguished by differences in the length of the palpi, as we shall presently see, and each species being known by peculiarities in its size, colour, and marking.

It is not intended in this paper to enter at length on an anatomical description of this insect, as very much that was said on the house fly will also apply here; but the antennæ and mouth organs must receive special notice. The former are composed of fourteen joints, the first of which is very large and almost globular; following this, there are eleven short joints in the male and two long ones, as shown in Fig. 4*a*, all of which, except the last, are furnished with a whorl of hairs, very long in the male insect, but short and scanty in the female, by which means the sexes may be easily known. It should be observed that in the male the last whorl springs from near the base of the last joint but one, as do all the whorls in the female. If this be not attended to, the joints may easily be made out to be fifteen, and not fourteen as stated. From the base of the rostrum, to be presently described, a pair of jointed palpi arise. In the genus *Culex*, which most frequently infests our bedrooms, the palpi of the male are slightly longer than the rostrum, and densely clothed with hair (Fig. 4), but those of the female are very short (Fig. 27). In the genus *Anopheles*, however, which is frequently found, the palpi are of equal length with the rostrum in both sexes, club-shaped at the tips in the males, and covered with a very short pile of hair (Fig. 28). These palpi are, according to Professor Westwood, the maxillary palpi, being attached to the base of the maxillæ. We must now look at the rostrum, as it is called, or trunk of the gnat. This is the instrument with which it inflicts its painful bite, and it is remarkable that only the females possess it in its entirety: that is, with all the parts needful for the development of the blood-sucking propensity, the males being quite harmless. In both sexes these parts consist of those usually found in the mouths of insects, viz., the labium or lower lip, the labrum or upper lip, the tongue, a pair of mandibles, and a pair of maxillæ; but in the males the three latter organs are suppressed, they possessing only the labrum and labium. We have seen from the examples of the cockroach and the house fly how different an appearance the same organs may present in different insects, and the gnat will furnish us with another example of this endless diversity. The mouth is, as in all the Diptera, suctorial, for although we speak of the bite of the gnat, it is really only a puncture that is inflicted, and not a true bite. Its most prominent part is the labium (Fig. 27), a long flexible organ proceeding from the front of the head, and deeply grooved on its upper surface for the reception of the remaining ones (Fig. 29). [Compare this with the grooved labium of the house fly.] At its extremity it bears three minute lobes (Fig. 30), the two outermost of which are probably the same organs that received such wonderful development in the fly, but are here much reduced both in size and importance. Within the groove lie six very minute lancets or needle-shaped pieces, only to be seen with the aid of a good microscope and a considerable amount of pains in separating them from one another. The largest of these is the labrum (Figs. 27, 31), which is broad at the base and slightly grooved at the tip; and within, or closely applied to it, lies the tongue, which Mr. Westwood describes as ribbed up the middle. We know that in the fly the tongue carries a tube, by which the salivary juice is conveyed to the mouth, and it is probable that this is the case also in the gnat, and that it is the cause of the extreme irritation which accompanies the gnat's bite. The other four parts

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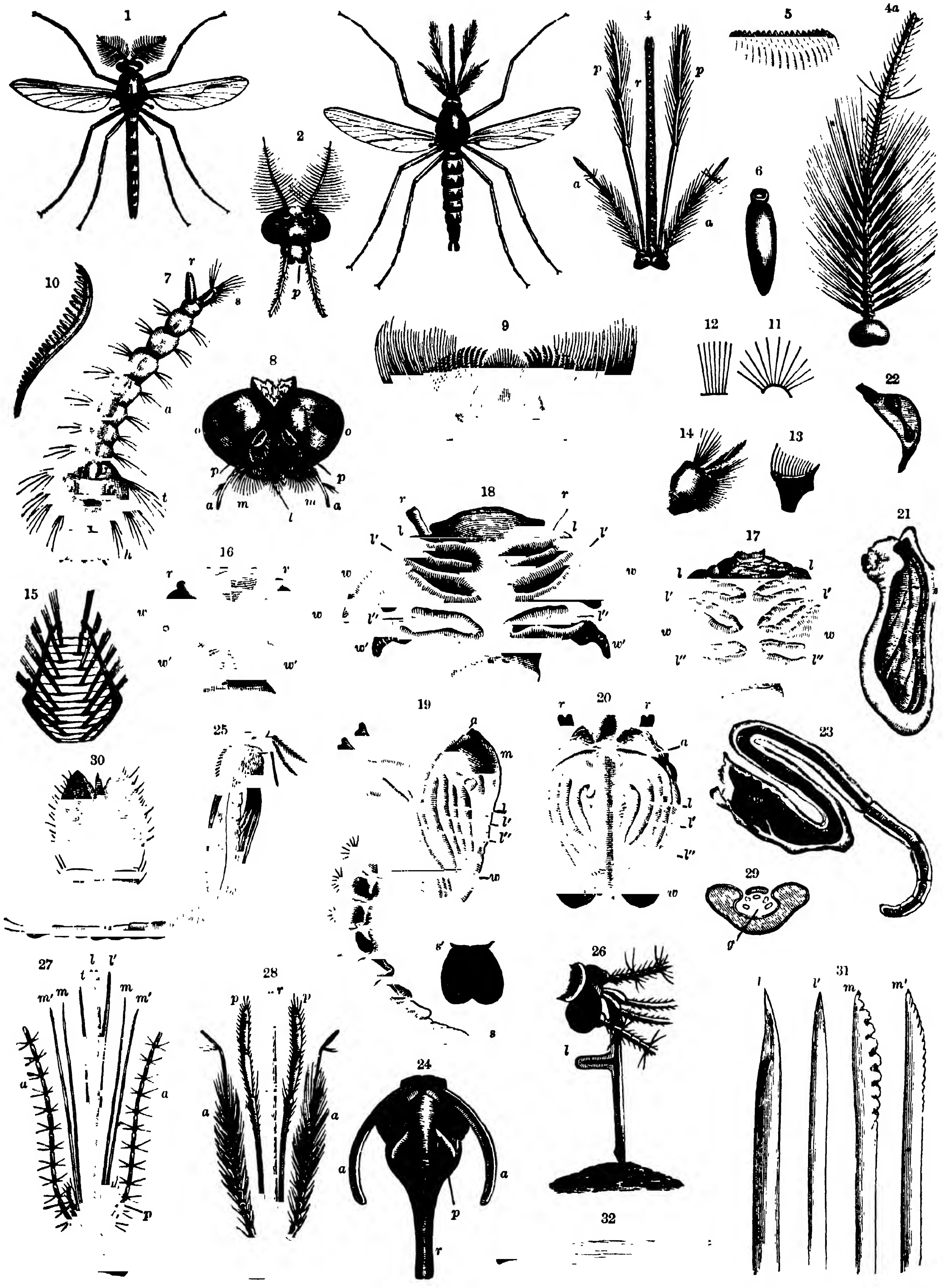
* "A House Fly:" "Science for All," Vol. IV., p. 22.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VARIOUS PARTS OF A GNAT.

(Explanation of Figures will be found on p. 230.)

are a pair of maxillæ and a pair of mandibles, the latter serrated at the tips, and all of them extremely fine (Figs. 27, 31). The following is Westwood's account of the manner in which the puncture of the gnat is effected :—" Taking its station upon an uncovered part of the skin, with so light a motion as not to be perceptible when it alights (although it will not hesitate to make its attacks occasionally through our thick clothing), it lowers its rostrum, and pierces the skin by means of its exceedingly slender needle-like lancets, which are barbed at the tips, and as by degrees it pushes these deeper into the skin, the lower lip or sheath in which they were enclosed when at rest, becomes more and more elbowed towards the breast, until the whole length of the lancets are introduced into the skin " (Fig. 26).

It remains to add that the rostrum and the nervures of the wings are clothed with scales (Fig. 32), similar to those which confer so much beauty upon the wings of butterflies and moths.

EXPLANATION OF FIGURES (*See* p. 229).

Fig. 1.—Chironomus plumosus, slightly magnified.
Fig. 2.—Head of Ditto, showing *p*, the Short Proboscis.
Fig. 3.—Male Gnat, slightly magnified.
Fig. 4.—Head of Ditto : *aa*, the Plumose Antennæ ; *pp*, the Palpi ; *r*, the Rostrum.
Fig. 4*a*.—Antenna of Ditto, showing the Joints.
Fig. 5.—Egg-float of Gnat. (*After Réaumur*).
Fig. 6.—Single Egg. (*After Réaumur*).
Fig. 7.—Larva of Gnat : *h*, the Head ; *t*, the Thorax ; *a*, the Abdomen ; *r*, the Respiratory Appendage ; *s*, the Fan of Hairs on the last Segment.
Fig. 8.—The under Surface of the Head of the Larva : *aa*, the Antennæ ; *l*, the Labrum ; *mm*, the Mandibles ; *pp*, the Labial Palpi ; *oo*, the Eyes. The Maxillæ are too small to be shown here.
Fig. 9.—The Mandibles and Labrum.
Fig. 10.—One of the Combs.
Figs. 11, 12.—Diagrams illustrating the manner in which the movements of the Mandibles are effected ; Fig. 11 open ; Fig. 12 closed.
Fig. 13.—Maxilla separate.
Fig. 14.—Labial Palp.
Fig. 15.—Gridiron Organ supporting Terminal Fan. (The bases of the hairs only are shown)
Fig. 16.—Upper Surface of Thorax of Larva, showing Limb-cases of the Pupa in course of formation : *ww*, the wing cases ; *w'w'*, those of the Halteres ; *rr*, the Respiratory Appendages.
Fig. 17.—Lower Surface of Ditto : *ll*, *l'l'*, *l″ll″*, cases of the three pairs of Legs ; *ww*, as before.
Fig. 18.—The same more highly magnified, the Larval Integument removed, and the wing cases, &c., drawn apart for their better display ; letters as before.
Fig. 19.—Pupa of Gnat, side view ; the limb cases of the Thorax lettered as in the Larva, Figs. 16 and 17 : *a*, Antenna Cases ; *m*, those of the Mouth Organs ; *s*, Swimming Leaflets of Abdomen ; *s'*, Ditto, front view.
Fig. 20.—Thorax of Pupa, front view ; letters as before.
Fig. 21.—Wing case of Pupa, with wing forming inside.
Fig. 22.—Haltere case, with Haltere.
Fig. 23.—Leg case, with Leg.
Fig. 24.—Cases of Mouth Organs : *a*, Antennæ ; *p*, Palpi ; *r*, Rostrum. (Female.)
Fig. 25.—Gnat escaping from Pupa. (*After Réaumur*).
Fig. 26.—Gnat sucking blood. (*After Réaumur*) : *l*, the bent Labium.
Fig. 27.—Antennæ and Mouth Organs of Female Gnat : *a*, Antennæ ; *p*, Palpi ; *l*, Labium ; *l'*, Labrum ; *mm*, Mandibles ; *m'm'*, Maxillæ ; *t*, Tongue.
Fig. 28.—Mouth Organs of Anopheles maculipennis, Male ; *r*, rostrum ; other letters as before.
Fig. 29.—Section of Mouth Organs of Female Gnat, showing Labrum and Lancets lying in the groove *g* of the Labium.
Fig. 30.—Extremity of Labium, with Lobes.
Fig. 31.—Lancets of Anopheles maculipennis highly magnified ; lettered as in Fig. 27. Only the tips are shown.
Fig. 32.—One of the scales from the wing.

HEAT POWER.

By W. D. Scott-Moncrieff, C.E.

THE distinction which exists between *power* and *work* has already been explained, and in a former paper* illustrations were given of how the one form of energy is converted into the other.

First of all, the heat of the sun raises the water from the ocean in the form of clouds, and these, being blown hither and thither, are at last condensed upon the cold surfaces of mountains and uplands in the form of rain. This leads to the formation of lakes and water-courses at high altitudes, and so the aqueous particles that once formed the clouds become, in course of time, an available source of energy and work.

Now, although the heat of the sun is the first step in the cycle of operations which finally led to the revolutions of the water-wheel, yet that apparatus cannot be spoken of as a heat engine. We shall now consider the case of heat, not acting through the medium of the clouds and the winds, but directly through channels expressly devised to take advantage of it by the ingenuity of man.

Although analogies in science are not generally to be relied upon as a very accurate means of conveying information, they are nevertheless so apposite at times that one cannot do better than make use of them. The particular method that has been adopted to illustrate the meaning and application of the terms *power* and *work* in previous papers, more especially the one on the *water-wheel*, recalls a well-known comparison between the underlying principles of energy. This illustration was made use of by the famous French philosopher Carnot. As his name is associated with some of the most valuable contributions that have ever been made to our knowledge of heat, we cannot be far wrong in drawing the attention of the reader to the analogy which he makes use of. Accordingly we give it as quoted by the late Professor Clerk Maxwell in his treatise on the theory of heat:—"Carnot illustrated his theory very clearly by the analogy of a water-mill. When water drives a mill, the water which enters the mill leaves it again unchanged in quantity, but at a lower level. Comparing heat with water, we must compare heat at high temperature with water at a high level. Water tends to flow from high ground to low ground, just as heat tends to flow from hot bodies to cold ones. A water-mill makes use of this tendency of water, and a heat-engine makes use of the corresponding property of heat." Now, while this analogy is exceedingly useful, as it conveys to the mind of the reader how two things, so utterly unlike each other as water stored at a high level and heat at a high temperature—the one of which is a substance and the other is not—have still much in common when looked upon as sources of energy, it is very misleading in one particular. Carnot believed that heat was something in the nature of a substance, and so his analogy of the water-wheel carried him too far. It was very difficult to prove by experiment that the quantity of heat after it had performed some kind of work, such as turning a wheel, was really changed in quantity, and had become less, and in this way differed essentially from the case of the water, the amount of which remained the same. But in 1862 it was shown by Hirn, experimentally, that in a heat-engine the quantity of heat that is emitted is less than that which is received; and it was only the unfortunate belief in what is not true with regard to heat being a substance, that led to the confusion of ideas about the quantity of heat and the quantity of water. We will now see how far the analogy of the heat-engine and the water-mill holds good, as it appears to us to be the best mode of illustrating heat power, in spite of the error which was made by Carnot.

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* " A Water Wheel : " " Science for All," Vol. III., p. 249.

First of all, then, we must fix our thoughts on the meaning of what we are speaking about. The subject of the present paper is heat *power*, or, in other words, that form of energy which is associated with the phenomena of heat. Now, as heat is itself the element of force or energy, we do not require to consider anything but its quantity and its intensity, and the range through which its temperature passes when cooling, in order to be able to calculate exactly the amount of available power it is capable of turning into work. In other words, the measure of the heat in respect to quantity and temperature is the measure of its theoretical energy. But in the case of water and the water-mill, the substance water is nothing but a vehicle through which force is exerted; if we double the quantity of water at a given level we certainly double its capacity for work; but this is true only in the same sense as, if we double the quantity of a hot substance, we double the available energy as well. The real measure of the force in the one case is the quantity and intensity of the heat, and in the case of the water, the quantity of force represented by the amount of the water, and the distance through which the force of gravity acts upon it. The water-wheel, then, ought more correctly to be spoken of as a gravity engine, which had its origin in the heat of the sun, while the heat engine is an apparatus by which heat is converted into work without the interposition of an intervening force. The changes that can be rung upon such illustrations are numberless, because they run through every condition of matter in which it is either the recipient, or the storehouse, or the dispenser of energy, whether we find our example in a cannon-ball in motion, or in water at a high level, or the magnetism of a compass, or the properties of chemical agencies, or the elasticity of springs, or the heat of a hot substance. The purpose of Carnot's analogy will really have been served if it conveys to the mind of the reader the exact comparison that can be made between water at a high level and a substance at a high temperature. In the first place, they are both storehouses of energy, that may be measured by the quantity of the water and the quantity of the substance, multiplied by the available height in the one case, and the available temperature in the other. Secondly, just as the water at the high level may have additions made to the total amount of its available energy, if it happens to be surrounded by streams that flow towards it and add to its quantity and its height, so a hot substance, if surrounded by still hotter bodies, may have its available energy added to by the tendency of the hotter bodies to part with their heat, and add to the quantity of the heat in the hot substance and to the intensity of its temperature as well. And if, on the other hand, the water at the high level is placed in an elevated hollow from which the ground slopes downwards in all directions, then, again, we have an analogy between its tendency to flow away and the case of a hot body surrounded by colder ones, to which it is continually dispensing its temperature and thereby reducing its energy. Still further, it will be well to notice that, just as it is necessary to place a wheel in a suitable position in order to turn the energy of the water into useful work, so a suitable apparatus is necessary in the case of the heat, in order that we may take advantage of it for any practical purpose.

We have made use of the analogy between a heat-engine and a water-mill in order to convey to the mind of the reader the general connection which exists between one sort of force and another. We will now go on to see how heat-power can be referred to some standard by which its amount can be measured. Just as it is necessary that we should know about two things in the case of water-power, viz., the quantity of the water and the distance of the available fall, so in calculating heat-power we must know the quantity of heat and its available range of temperature.

The first process, as has already been explained in these pages, is conducted by means of the calorimeter, the second by the thermometer. In these instruments the action of heat is measured in the one case by its capacity to produce a measurable amount of change in the condition of a substance, such as melting ice, and in the other a measurable amount of expansive force, as in the case of a column of mercury. Now although these experiments are essential to our knowing anything exactly about the phenomena of heat, they are used to measure it in many cases under circumstances in which heat-power does not exist in a practical form. For instance, an inquiry into the specific heat or the quantity of heat in different substances, at standard temperatures, is like measuring water which may or may not be available, from its situation, to drive a water-wheel. We will confine ourselves, therefore, in the present paper, to the case of heat acting, on suitable substances, in a manner that renders it available as heat-power. First, then, we may at once dispense with a consideration of the effect of heat upon matter in a solid state, in the sense of the solid being used as the *direct* vehicle of force. We know that if we heat a bar of iron it will expand, and we know also that when it is allowed to cool it will contract, and that in this alternate movement of the bar there is the primary motion that takes place in the reciprocating action of a steam-engine. But at the same time we should never look to a bar of iron, or any other solid substance, as an available prime mover. It would be equally impracticable to attempt to find in any liquid substance a *direct* vehicle for conveying heat-power into the working of an engine. A rise in temperature, when the fluid was free to evaporate, would very soon result in its entire disappearance in the form of vapour, and the equivalent of the heat would be found in the amount of energy absorbed in carrying on the operation of changing the condition of the liquid. It is to the gaseous state of matter alone we must look for a practical vehicle for the conveyance of heat-power into work, and the most economical type of heat-engine will be found when we discover a medium that absorbs the least quantity of heat in proportion to the nett amount of useful work performed. Now in this respect an air-engine is by far the most economical, because nature has provided in this case a substance which is in a permanently gaseous state, whereas in a steam-engine a great amount of heat has to be expended in order to obtain the condition of an elastic fluid, especially if we start with water in the solid condition of ice, which has first to be converted into a liquid and afterwards into steam.

These facts have acted as a stimulus to inventors and men of science to discover, if possible, some practical method of using hot air instead of steam as a motive power, and a few words will therefore not be out of place to show how heat affects a permanent gas. The diagram (Fig. 1) is a rough illustration of an imaginary instrument, which is called the air-thermometer. It differs from the apparatus used by Galileo, inasmuch as he made his serve the purpose of an ordinary instrument for measuring temperature, in the same way that we employ a column of mercury, whereas the air-thermometer, of which we are now about to speak, is employed as a visible illustration of what would take place if certain phenomena could be produced.

The first step that was necessary in the graduating of an imaginary thermometer which would have an absolute zero, and that should represent no heat, was to know the effect of a given change of temperature upon the unit volume of a permanent gas. This was discovered by several men of science about the same period; and as the effect of heating follows an invariable law in the case of all gases, it is known as the second law of gases, and is generally associated with the names either of Charles or of Gay-Lussac. It asserts that any gas under a constant pressure is dilated to the same extent when its temperature is raised from the freezing to the boiling point of water. The experiments of men of science have been checked one by another, and the result can therefore be depended upon as trustworthy. Between 0° Centigrade and 100° C. the volume of a permanent gas such as air, expands from 1 to 1·3665. In other words, if sixty cubic inches of air, at any pressure, were heated from the freezing to the boiling point of water, it would be found that the vessel containing it would require to have a cubic capacity of about eighty-two inches to contain the air if the original pressure were to be neither increased nor diminished. Now the ratio of the dilatation to the temperature having been discovered, it will be seen that it is no longer difficult to graduate an imaginary air-thermometer so that the position of an absolute zero can be fixed. Supposing we start from the point *a*, Fig. 1, as the unit of volume, and suppose that the column of air is just one foot long, then it will be, according to the law of Charles, 1·3665 feet long when it has been heated to the temperature of boiling water, and the reading will then be 100° C. for temperature and 1·3665 for volume, at *b*. If we then go on heating it till the temperature has reached 200° C. the volume of the gas will have increased (the pressure remaining constant) to 1·733 feet; and when the column of air is two feet long the temperature will be 273° C. Now reasoning in the same way downwards from the point of unit of volume at *a*, and reversing the operation by abstracting heat instead of adding it, we find that at the point *d*, at which we have a temperature less than that of freezing by 100° C., the column of air will no longer be 1 foot long at the constant pressure—it will be 1 foot less a fraction of ·3665 of a foot, or ·6335. If we again extract temperature to the extent of 100° C., then we must again deduct a similar fraction of the volume from what remains, so that at the point *e*, and at the temperature of − 200°, the volume has been reduced to ·267. Here we can no longer extract 100° C. of heat, because if we did so there would be less than nothing left. But by a simple application of the Rule of Three we arrive at the minus temperature that leaves theoretically no volume, and this will be found to be − 273° C., or − 460° Fahr. Here, then, we have a thermometer which serves the purpose of a real instrument, in so far that it enables us to start from a supposed absolute zero, in which, according to the second law of gases, there should be theoretically no volume. Here the reader may be inclined to ask what all this has got to do with heat-power, which is the subject of the present paper. The answer is, that the total amount of the heat contained in the air is the exact measure of its energy or power; for although we are never likely to be able to show experimentally that at a minus temperature of 273° C. below freezing point there is absolutely no volume; still, all observation goes to prove the applicability of the law of Charles, at least as far as any observed temperature. In the words of Professor Clerk Maxwell, although we know nothing about the temperature which would be indicated by an air-thermometer placed in contact with a body absolutely devoid of heat, this much we are sure of, that the reading would be above − 459°·13 F.

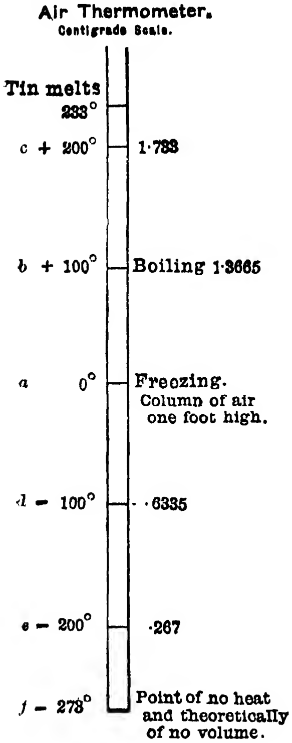

Fig. 1.—An Air-Thermometer.

We will now look at the diagram of the air-thermometer, not as a narrow column containing an elastic fluid, placed there with the object of measuring its movements, but as a great reservoir of a permanent gas. We will also take it for granted that when the unit volume of the gas is at freezing point the pressure is so low as not to be available as a motive power. In other words, we will suppose it to be like an accumulation of water near the level of the sea, which would be an effective source of power if it were raised to a great height, but which is incapable of being used as a vehicle for useful work in its existing situation. Now, so long as we heat the air, and allow it to expand, so that the pressure remains constant for every addition of temperature, we do very much the same as regards its available power as if we were to double the quantity of water in the reservoir near the sea-level. But suppose, instead of allowing the air to expand, we keep it confined, so that its volume cannot increase—we then discover that the increase of temperature has exactly the same rate of effect upon its pressure as it had upon its volume. In other words, instead of simply adding to the quantity of heat, as if we added to the quantity of water, we no longer add to the volume of the air, but we add to its pressure, or available power, just as if we raised the supposed unit quantity of water to an increased height above the level of the sea. In this way, when we have heated the air to 100° C. above freezing point, and kept its volume constant, we shall find that the pressure we started with, whatever it may have been—one pound or one ounce to the square inch—has been increased from 1 to 1·3665. It is clear, then, that here we have a range of available pressure, represented by the fraction ·3665, that may be turned into useful work, just in the same way that we might make use of an elevated weight, or the tension of a spring that has been wound up or compressed. Further, it must be observed that the effects of greater or less additions of temperature follow exactly the same law as in the case of the volumes referred to in the description of the air-thermometer, and that therefore when the temperature of a given volume of air has been raised from 0° C. to 273° C. without the volume or space occupied by the gas having been increased, then the pressure will be exactly doubled, just as the volume would have been if the vessel containing the air had been allowed to expand, and the pressure remained constant. Now these facts enable us to make important combinations between what is known as the first and second laws of gases, generally called the law of Boyle and the law of Charles. The first of these asserts that the product of the volume and pressure of any portion of gas always equals a constant quantity. If we double the volume we halve the pressure; if we halve the pressure we double the volume: if we double the pressure we halve the volume; if we halve the volume we double the pressure. The law of Charles asserts that "the volume of a gas under constant pressure expands when raised from the freezing to the boiling temperature by the same fraction of itself whatever be the nature of the gas."

Now as we know that the conditions of Boyle's law remain in force so long as the temperature is constant, but that when the temperature is increased it increases either the volume *or* the pressure in the proportion of 1 to 1·3665, for the range of heat represented by the difference between the freezing point and the boiling point of water, then the product of the volume and pressure must always be affected by the heat in this proportion. When, however, we are able to start from an absolute zero, as in the case of the air-thermometer, we are then enabled to simplify the expression of the two laws of Boyle and Charles, and assert that *the product of the volume and pressure of any gas is proportional to the absolute temperature.* Looking at this statement in relation to heat-power, we find it is equally applicable as a measure of energy, the amount of which we may also say is proportional to the absolute temperature. But this relationship between heat and heat-power enables us to go still further than the air-thermometer in fixing upon a theoretical absolute zero, or point of absolute heatlessness, which is the equivalent, from a *power* point of view, of water that cannot possibly reach a lower level. This temperature is arrived at by the knowledge we have of the relationship which exists between heat-power and heat-work already referred to in the papers on "Power" and "Work."* This is known as the mechanical equivalent of heat, in which a heat unit is the equivalent of a work unit, and we have only therefore to suppose that a heat-engine which has received a certain quantity of heat performs the total amount of work theoretically due to that heat in order to arrive at an absolute dynamic or power zero, which must be a heat zero as well. It will now be understood how many methods there are of measuring heat-power, and how they are all more or less analogous to the instance of the water-mill. In the one case the total available energy is the product of the weight of the water and the height through which it falls; in the other it is the quantity of heat to be obtained from an available range of temperature.

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* "Science for All," Vol. II., pp. 97 and 255.

HEARING.

By T. Jeffery Parker, B.Sc., A.L.S.,

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In studying any branch of science, one of the most essential points, if we have no wish to be involved in hopeless confusion, is to define clearly every word used in a scientific or technical sense, and to take care that, once defined, the same word is never made to do duty for some meaning different to that which it was originally intended to convey. One has to be particularly careful in the case of words in ordinary use, for these are often used in a more or less slipshod fashion, and unless strictly looked after are likely to prove very dangerous stumbling-blocks to the unsuspecting student. The present paper gives us at once a case in point. Asked what is the organ of hearing, one naturally replies, the ear: asked to define the ear, it is equally natural to point out that gristly and fleshy appendage at the side of the head, which a barbarian taste has decided shall be cut in the case of terriers for the sake of symmetry, pierced in that of human beings, for the insertion of some useful or ornamental article—snuff-box or earring.

But a moment's consideration will convince the most unthinking that the "ear" in this sense of the word is not the organ of hearing at all. For deaf people, or people rendered temporarily deaf by a plug of cotton wool or the like, have the "ear" as perfectly developed as any one. People who have had their ears cut off, and animals devoid of that appendage, such as birds, reptiles, and fishes, are, as common observation teaches, quite capable of hearing and distinguishing sounds. The sound of, for instance, a tuning-fork or a musical box can be made audible to deaf people by placing the instrument against their teeth, and the same thing can be shown by stopping one's ears tightly, and touching one end of a table or plank with the teeth, while another person gently scratches the other end of the piece of wood.

What all these facts show is, that the organ of hearing is something inside the head, and that the sound waves which give rise to an auditory impression may, as under ordinary circumstances, be transmitted through the tube which we see passing towards the interior of the head from the "ear," or may, if this their normal channel is closed to them, be transmitted through the bones of the skull.

We must distinguish, therefore, the *external ear*, or ear commonly so called, from the *internal ear*, or true organ of hearing. The former, although of great use, can be dispensed with; the latter is absolutely essential for purposes of hearing.

Let us now consider what are the essential conditions of our organ of hearing. What we call sound is due to vibrations of the air communicated with a certain degree of rapidity by the sonorous body; and that any sound should be audible to an animal, it is necessary, firstly, that there should be some part of the animal body so delicately poised, as it were, as to be set vibrating in unison with the sound, and secondly, that there should be, in connection with this same part of the body, a nerve able to transmit the vibrations to the brain. It is instructive to compare the essentials of an organ of touch with those of an organ of hearing. When any part of our body is touched, an impression is made on the skin, and this impression is communicated by a nerve to the brain: if the nerve is cut, that part of the body is quite without feeling. The skin, therefore, which is the great organ of touch, is able to receive and transmit to the brain, by its nerves, coarse vibrations, produced by actual contact. If any part of the skin could be made so sensitive as to be set vibrating by sound waves, it would become an organ of hearing, and its nerve would become an auditory nerve.

The internal ear of the higher animal is a structure of such extreme complication, that the best way to get a correct notion of hearing organs in general will be to consider the apparatus as it exists in the lower animals, where its structure, and the principles upon which it works, are sufficiently simple to be readily grasped.

No better animal can be selected to start with than the common lobster, as any one sufficiently interested in the subject can readily make out the main points of its hearing organ for himself, by sacrificing to scientific purposes a small and insignificant portion of a lobster salad.

The lobster has two pairs of feelers, one long—the antennæ, and one short—the antennules, projecting from the front of its head. If one of the latter be removed by inserting the point of a pocket-knife between its near end and the socket in which it works, it will be found to consist of three strong, hard pieces, placed one above the other and movably jointed together.

The last of these pieces, that farthest from the head in the entire animal, has attached to it two jointed filaments about two inches long. These form the feeler proper, being organs of touch.* The first joint of the feeler—that nearest the head—is considerably larger than either of the others, and presents on one—the upper—surface, an oval space which is not hard and rigid like the rest, but membranous, or rather horny, being formed of a substance called *chitin*, the same substance as that which forms the soft interval between the hard joints on the under side of the lobster's tail.

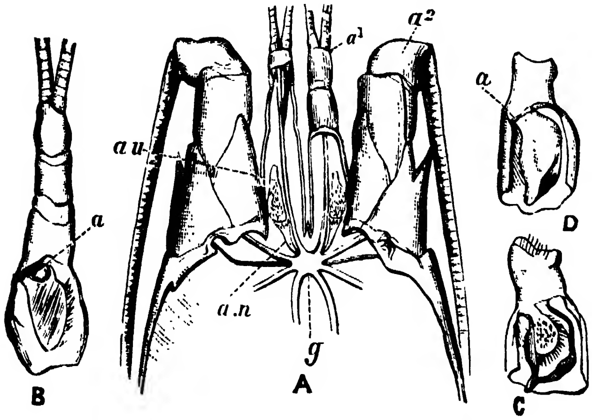

Fig. 1 —Hearing Organ of Lobster. (*After Farre.*)
A, Head of Lobster, to show relations of Auditory Organ and Nerve: *a*¹ Antennules; *a*², Antennæ; *au*, Auditory Organ; *a.n.*, Auditory Nerve; *g* Brain. B, Basal Part of Antennule, showing Position of Auditory Organ *a*, External Aperture. C, Auditory Sac *in situ*, cut open so as to show [illegible] of Auditory Hairs and Otoliths. D, Auditory Sac *in situ*, entire: [illegible] aperture

At the farther end of the same joint, and to the outer side of this space, is a little tuft of hairs; in the middle of this tuft is a small hole, into which a bristle or even the head of a small pin can easily be passed. If, then, the whole lower side of the joint is cut away, and the soft stuff which fills it scraped out, the bristle is seen to have passed into a little transparent bag of chitin, about a quarter of an inch long. On the lower side of this *auditory sac*, that is, the side we are now supposed to be looking at, there is a curved line of slightly different appearance to the rest of the wall. Careful dissection shows that the nerve passing from the brain to supply the feeler sends off a small branch to the curved line: this branch is the *auditory nerve* (Fig. 1, *a.n.*).

When the auditory sac is cut open it is found to be full of sea-water, in which are a number of little sandy particles, called ear-stones, or *otoliths*.

One more point about the structure of the organ. Underlying the whole hard shell of the lobster is a delicate red membrane, composed of minute protoplasmic bodies called *cells*, and answering to our own epidermis. A similar membrane forms a sort of outer coat to the auditory sac, and is continuous around the aperture of the sac with the membrane underlying the hard shell of the antennule, just as the shell itself is continuous with the chitin of the sac.

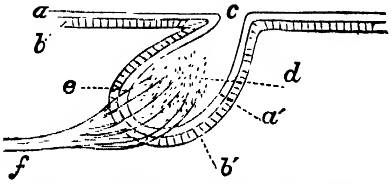

Fig. 2.—Diagram of Auditory Sac of Lobster.
a, Shell of Antennule; *a′*, Chitinous layer of auditory sac; *b*, Epidermis; *b′*, Epithelial layer of auditory sac; *c*, Mouth of sac; *d*, Otoliths; *e*, Auditory Hairs; *f*, Auditory Nerve.

To make out much more of the structure of the lobster's ear, it is necessary to have recourse to the microscope. If that portion of the wall of the sac containing the curved line is cut out and examined under a comparatively low power, a row of bodies called auditory hairs, or *setæ*, is seen to be attached all along the line, and to project into the cavity of the sac among the ear-stones. Each of these setæ is a beautiful feathery structure, consisting of a stem with a rounded base, which fits, ball-and-socket fashion, into a depression in the wall of the sac, and with a number of minute filaments corresponding with the barbs of the feathers, given off on either side. The whole seta is not more than $\frac{1}{60}$th of an inch in length. A specimen prepared with sufficient care, shows that to each seta proceeds a minute branchlet of the auditory nerve (Figs. 2, 3).

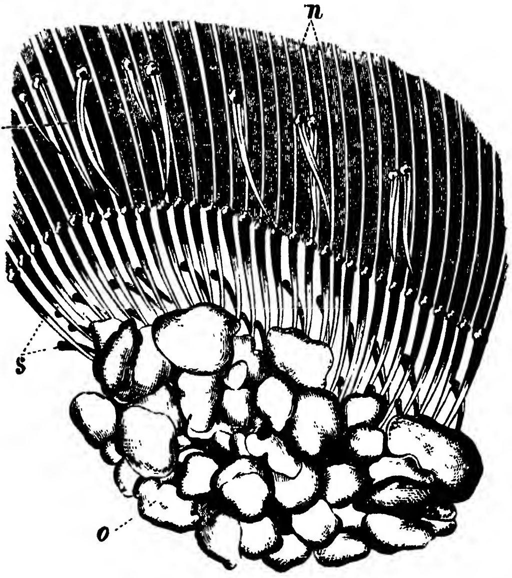

Fig. 3.—Portion of Auditory Sac of Lobster, highly magnified to show the Auditory Hairs. (*After Hensen.*)
n, Branchlets of Auditory Nerve; *o*, Otoliths; *s*, Setæ.

So much for the structure of the apparatus: now for the way it acts. Sound waves from any sonorous body in the lobster's neighbourhood will strike against the bottom joint of the little feeler. Of these waves, those striking against the hard parts will have little or no effect unless the sounding body be in actual contact, but those which strike the soft space already mentioned will set it vibrating, and the vibration, transmitted to the auditory sac, will produce a corresponding movement in its contained fluid. The same effect will be produced, but in a more marked degree, by waves entering the small external aperture. The movement of the fluid will cause the setæ to vibrate, and a nervous impulse will be transmitted along the auditory nerve, and so give rise in the brain to the sensation of hearing. The otoliths may assist in transmitting the vibration of the fluid to the hairs, or possibly may act as dampers.

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* And perhaps also of smell.

There is still something to be said about the anatomical relations of the sac. It communicates with the exterior by a small hole, so that its wall is directly continuous with the outer surface of the body, and the whole sac might not unreasonably, from examination of it in the adult animal, be looked upon as a portion of that outer surface tucked in. And that this is really the case is found by examining lobsters of different ages, when it is seen that very young specimens have no auditory sac at all, and that when this organ does arise, it arises by the upper wall of the first joint of the antennule being pushed in, as it were, so as to form a shallow depression; this depression deepening, forms at last a bag widely open to the outer air, and lastly, the bag itself growing faster than its mouth, the auditory sac of the adult is produced.

So that the wall of the sac is just a bit of the "shell," with its underlying epidermis, turned in; and the auditory hairs are nothing more than the hairs with which many parts of the lobster's body are covered—the tail, for instance, is fringed with them—specially modified for purposes of hearing, by acquiring great delicacy and by being very beautifully hinged.

There is no reason whatever why hairs on the free surface of the body should not have this same accurate adjustment, and so serve for hearing; and indeed it is thought by some competent authorities that certain fringed hairs on the surface of the antennules and of the tail of the prawn, closely resembling the hairs of its auditory sac, really do serve the purpose of hearing. If this be true, the prawn has some auditory hairs which have been tucked into a sac and others which have not. Of course the former position must be the most suitable for the purpose, for in the first place, the delicate hairs are protected from injury, and in the second place, the sac itself probably acts as a resonator, and augments the force of the sound waves.

How then do the otoliths come about, since there are no representatives of them in connection with the hairs on the free surface of the body? I mentioned that these were sandy particles: they are, in fact, just minute sand grains, such as are found on the sea bottom where the lobster lives, and the question suggests itself, are they actually formed by the lobster, or are they taken in from the outside? If so, how?

This question was settled in a very ingenious way by Dr. Hensen. It is known that lobsters and their allies—prawns, crabs, &c., shed their shells annually, and that with the shell of the antennule the chitin of the auditory sac is shed too, and with it, of course, the otoliths, so that for a time after casting the shell, the animal has a soft exterior, a soft auditory sac, and no otoliths.

Hensen took some prawns which had just shed their shells, and put them in an aquarium, the bottom of which was covered, not with sand, but with some minute, easily recognisable crystals. In this way he made sure that the animals were not supplied with sand. He examined them after a short time, and found that they all had in the auditory sacs some of the crystals, which now acted as otoliths. They had taken them in by plunging their heads into the mass of crystals, and moving about until some of the latter were forced in.

Another form of auditory organ, at first sight quite different to that of the lobster, is found in the common little fresh-water bivalve called *Cyclas.* If this little creature is watched during life it is seen to protrude from between its valves a fleshy, tongue-like process, called its foot. If now a Cyclas is taken from the water, its valves removed, and its foot examined under the microscope, there is seen in about its middle a little rounded cavity containing a small particle in constant vibration. The cavity is the auditory sac of the Cyclas; and the vibrating particle is its otolith (Fig. 4).

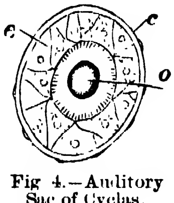

Fig 4.—Auditory Sac of Cyclas. (*After Leydig.*)

c, Auditory Capsule; *e*, Ciliated Epithelium; *o*, Otolith.

Careful examination shows that this sac consists of a delicate wall lined with minute cylindrical cells, from each of which a number of delicate filaments, called *cilia*, project into the cavity of the sac. These filaments are in constant motion waving to and fro like the similar bodies in a wheel-animalcule, and it is by the motion thus set up that the otolith is kept in a perpetual tremble in the fluid which fills the sac.

Comparing the auditory sac of Cyclas with that of the lobster, it is evident that the ciliated cells lining the former answer exactly to the cells of the epidermis forming the outer layer of the latter. But in Cyclas there is no chitinous inner coat to the sac, there are cilia instead of auditory hairs, and the sac is completely closed instead of opening to the exterior.

The last-named circumstance seems to indicate a radical difference between the two organs, for it hardly seems likely, at first sight, that a closed sac embedded in the very substance of the foot can have any connection with the epidermis covering the foot. But there is every reason to believe that the sac in this case also, arises as a pushing-in of the epidermis, a sort of tunnel being formed, the far end of which dilates into the sac, while the remainder of it disappears, all evidence of the original connection of the auditory sac with the exterior being thus obliterated. Here again, therefore, the sensory surface is a specially modified portion of the general surface of the body.

Another easily obtained auditory organ is that of any common bony fish, the cod, for instance. Most people must have noticed a little white, flat stone with a crinkled edge, looking very like glazed porcelain, which occurs in the interior of a cod's head, apparently quite loose. This little stone is the ear-stone, or otolith of the fish (Fig. 6). To make out its real position and relations, a dissection, or series of dissections, is necessary.

In the hinder part of the cod's skull, on each side of the brain case, is a large bony projection, containing an irregular cavity, in free communication, in the dry skull, with the cavity in which the brain is lodged. This bony mass is the auditory capsule. If, in a fresh head, the bone composing it is broken away bit by bit, the cavity is found to contain, floating in a watery fluid called *perilymph*, the fish's auditory organ, or, as it is often called from its complexity, *membranous labyrinth* (Fig. 5).

This consists of a delicate membranous sac, of ovoidal shape, called the *vestibule*, connected with which are three tubes bent into the form of a half-circle, and hence called *semicircular canals*. Of these, two have a vertical position, one at the front, the other at the hinder end of the vestibule; the third is horizontal, and attached to the outer wall of the sac. The two vertical canals are joined with one another for a short distance, so that the two canals only have three openings between them into the vestibule: at the end farthest from its fellow each canal is swollen out into a little bulb, the *ampulla*. The horizontal canal is quite independent of the other two; like these it has an ampulla placed at its anterior end.

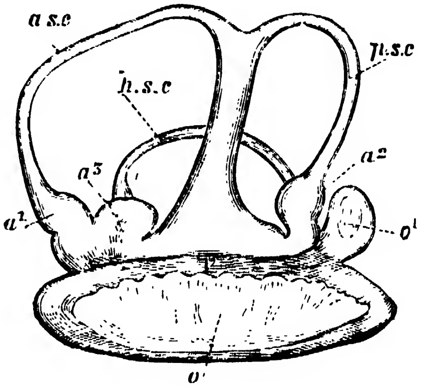

Fig. 5.—Auditory Organ of Cod.

a^1—a^3, Ampullæ; *a.s.c*, Anterior Semicircular Canal; *h.s.c*, Horizontal Semicircular Canal; *p.s.c*, Posterior Semicircular Canal; *o*, Otolith; o^1, Smaller Otolith; *v*, Vestibule.

The large otolith already mentioned lies within the vestibule, floating in the fluid (*endolymph*) with which that cavity is filled. Besides the large otolith there is another, of much smaller size, and therefore easily overlooked.

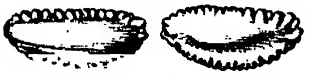

Fig. 6.—Otolith of Cod.

A large nerve (the auditory nerve) proceeds from the brain of the fish into the auditory capsule, and there branches out, twigs from it passing to the vestibule and to the ampullæ of the canals.

Microscopic examination shows that the membranous labyrinth has a lining of cells, resembling in all essential respects those we have already found in the lobster and the Cyclas. In the ampulla and certain parts of the vestibule these cells give rise to long, stiff filaments, which project into the endolymph. The ends of the nerves split up into extremely fine branches, one of which, in all probability, becomes directly connected with each of the cells (Fig. 7).

Hearing takes place in much the same way as in Cyclas: the sound-waves breaking against the fish's head are transmitted through the substance of the latter to the perilymph, thence to the labyrinth itself and its contained endolymph. The vibrations of the endolymph and of the otoliths affect the hair-like processes of the auditory cells; in these the vibrations are converted into a nervous impulse, which is conveyed along the auditory nerve to the brain, and there gives rise to the sensation of hearing.

Like the simple auditory sac of the Cyclas, the fish's complicated hearing-apparatus is just an inturned bit of skin. The auditory organ makes its first appearance as a little pit on the surface of the head; the pit deepens into a canal, the outer part of which becomes obliterated, while the inner is converted into the whole labyrinth. In some fishes, such as the shark, dogfish, and skate (Fig. 8), a fine tube--possibly representing the above-mentioned canal—is present throughout life, placing the cavity of the vestibule in communication with the surrounding water.

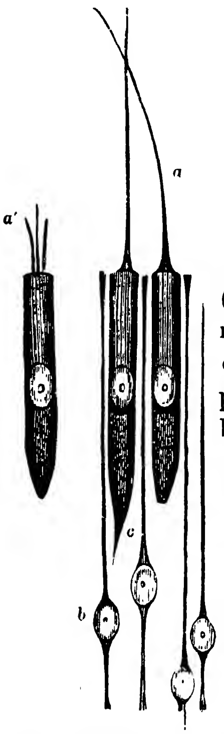

Fig. 7.—Auditory Cells of Fish.

a, a^1, Audit Hairs; c, Columnar ells; b, Spindle- ed Cells ly een the Columnar Cells

In the higher animals—in a sheep, a rabbit, a dog, or a man —the auditory organ has essentially the same structure as in the fish, in that it has a vestibule with three semicircular canals. But there is an important addition in the form of a long tube, blind at one end, and coiled up into a snail-shell-like figure of two and a half turns. This structure is called from its form the membranous *cochlea*. In all probability it has something to do with the appreciation of musical tones, though how it performs this function is by no means clear. Probably certain peculiar structures, called "hair-cells" and "rods of Corti," have something to do with it (Fig. 9).

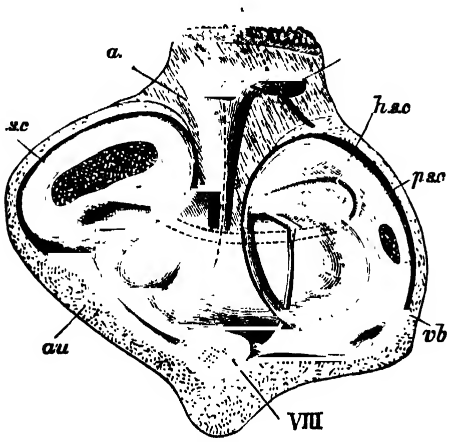

Fig. 8.—Auditory Organ of Skate. (*After T. J. Parker.*)

lle; *a s.c.*, Anterior Semicircular Canal; *h.s.c.*, Horizontal , Posterior do. do.; *vb*, Vestibule; *a*, Canal leading from rds Exterior; *s*, Bristle passed through the small Aperture om *a* to the Exterior; VIII, Auditory Nerve.

Both labyrinth and cochlea contain endolymph, and are contained in a cavity hollowed out in the auditory capsule, the cavity being filled, as before, with perilymph. But in this case the cavity is no longer irregular, but of almost exactly the same shape as the membranous organ it protects. Moreover, the bone immediately surrounding the cavity is of a particularly hard and ivory-like texture, while the next outer layer is full of cavities, and consequently comparatively soft. So that the surrounding soft bone can be cut away, leaving the hard bone immediately surrounding the labyrinth, and this hard bone is then found to have quite the same shape as the membranous organ. A "bony labyrinth" and "bony cochlea" are therefore often spoken of, in contradistinction to the membranous parts of the same name.

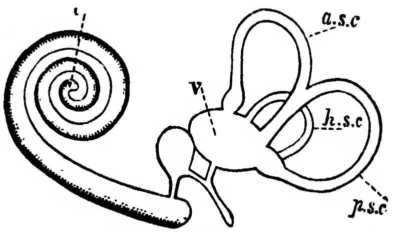

Fig. 9.--Diagram of Membranous Labyrinth and Cochlea of a Mammal. (*After Waldeyer.*)

a.s.c., Anterior Semicircular Canal; *h.s.c.*, horizontal do. do.; *p.s.c.*, Posterior do. do.; *v*, Vestibule; *c*, Cochlea.

In the case of the labyrinth proper—vestibule and canals—the bony case fits pretty closely, and the perilymph-containing cavity between the bony walls and the membranous structures is very small. But the bony cochlea is of considerably greater diameter than the structure it contains, and the membranous cochlea is, as it were, jammed close against the surrounding bone on one side, so that on the other side a considerable space is left. This space is not single, but is divided into two compartments, an upper and a lower, by a bony partition, which stretches inwards from the wall of the osseous to that of the membranous cochlea. This partition is, like the cochlea itself, spiral, and consequently the whole cochlea, if cut across, is seen to consist of three separate passages running close alongside one another; a middle one, that of the membranous cochlea, containing endolymph, an upper, called the *scala vestibuli*, containing perilymph, and a lower, the *scala tympani*, also containing perilymph. The two latter communicate with one another at the apex of the spiral (Fig. 10).

I have hitherto spoken of the cavity in the bony apparatus as if it were completely closed in by bone all round; but this is not strictly true. At two places the bony wall is deficient, two little holes being present, which are covered over by very thin membranes. The larger of these is called, from its shape, the "oval window" (*fenestra ovalis*), the smaller the "round window" (*fenestra rotunda*).

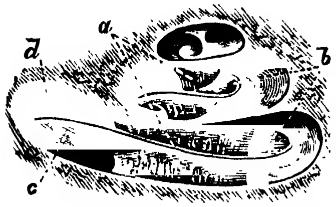

Fig. 10.– Bony Cochlea, with part of its Wall removed.
a, Central Pillar; *b*, Spiral Partition; *c*, Scala tympani; *d*, Scala vestibuli.

The membranes which may be said to form the glazing of these windows separate the cavity of the bony labyrinth from a large and comparatively simple chamber, called the *tympanum*, or ear-drum. The bony wall containing the two windows forms the inner boundary of this drum-cavity; externally it is produced outwards into a canal, the external auditory passage, which opens on the side of the head, and is surrounded by the external ear. It is this canal which we see in our own "ear," leading somewhere into the interior of the head (Fig. 11).

There is a second canal in connection with the tympanum, called the eustachian tube. It passes from the front part of the cavity, and passing forwards and downwards opens into the mouth. So that if there were nothing else to be mentioned in connection with the tympanum, there would be free communication between the ear and the mouth.

But as a matter of fact, there is no such communication. For, stretched across the inner end of the external auditory passage, just where it joins the drum-cavity, is a tough skin, the drum-membrane, which completely separates the cavity of the external passage from that of the drum.

Attached to the inner side of this membrane is a little bone, the shape of which is seen in Fig. 12 to bear some sort of resemblance to a hammer. It is hence called the hammer-bone (*malleus*); its "handle" is attached to the drum-membrane, its "slender process" projects into a cleft in the bone forming the wall of the drum, and its head is articulated or jointed to a second small bone, called the "anvil" (*incus*), rather from the fact that the head of the hammer is applied to it than from any resemblance it bears to an anvil. This anvil bone has, like the hammer, two projections or "processes," a long and a short; to the long process is articulated a tiny grain of bone, called the "orbicular bone" (*os orbiculare*), and to this again is jointed a bone which is very rightly called the "stirrup" (*stapes*), since it has precisely the shape of that article. The foot-plate of the stirrup is firmly fixed to the membrane of the oval window.

Now as to the use of all this complicated apparatus, which in the higher animals is superadded to the essential organ of hearing. The sound-waves enter the external auditory passage, some of them being reflected into it by the external ear, which acts as a natural ear-trumpet to catch the sound. Arrived at the bottom of the passage, the waves strike against the drum-membrane and set it vibrating; its vibrations give a corresponding backward and forward movement to the malleus, and the motion is communicated through the incus to the stapes, which, being fixed to the membrane of the oval window, gives to the latter an in-and-out movement. This last movement of course affects the perilymph, and then everything takes place as in the codfish. The improvement in the mammal consists in the addition of a special, delicately balanced apparatus to communicate external

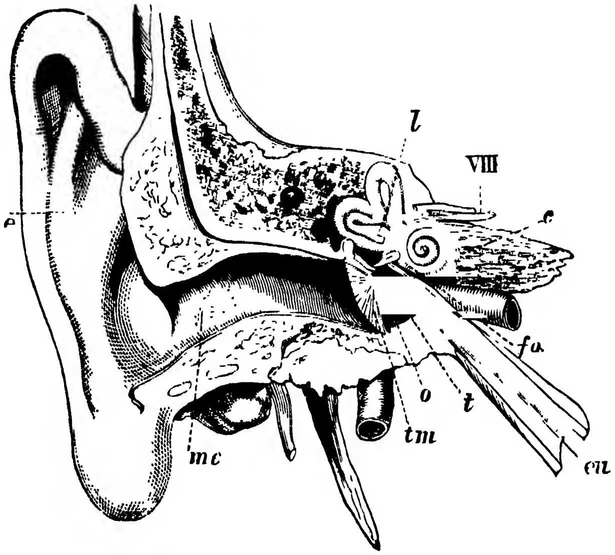

Fig. 11.—The Entire Hearing Apparatus in Man.
e, External Ear; *m.e*, External Auditory Passage; *l*, Bony Labyrinth; VIII, Auditory Nerve; *c*, Bony Cochlea; *f.o.*, Fenestra Ovalis; *eu*, Eustachian tube; *t*, Tympanum; *o*, Auditory Ossicles; *t.m*, Tympanic Membrane.

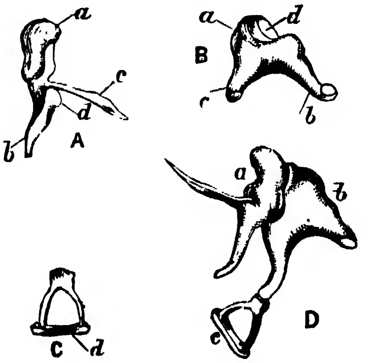

Fig. 12.—The Auditory Ossicles of Man (*left side*.)
A, *Malleus*: *a*, Head; *b*, Handle; *c*, Slender Process; *d*, Short Process. B, *Incus*: *a*, the body; *b*, Long Process with the orbicular bone attached at its end; *c*, Short Process; *d*, Articular Surface for head of malleus. C, *Stapes*: *d*, the Base; D, the foregoing in their natural connections, as seen from the outside: *a*, Malleus; *b*, Incus; c, Stapes. (*Twice natural size.*)

vibrations to the perilymph. The round window serves for the vibrations of the perilymph to spend themselves against; every time the oval window is thrust in, the perilymph, instead of undergoing compression, pushes out the membrane of the round window to a corresponding extent, and *vice versâ*.

The above account of the organ of hearing aims at giving the reader some notion of the manner in which, and of the apparatus by which, the function of hearing is performed. I have purposely not attempted to go into details of structure, or into the endless modifications of the auditory organs in the various groups of animals, but have judged it best to select a limited number of common and easily obtainable animals, from the consideration of which the main types of auditory organs may be understood. Any one with the least skill in dissection can make out at any rate most of the points described for himself, and those who are unable to do this can see preparations of the larger structures at any well-equipped anatomical museum, such as those of the Universities, or that of the Royal College of Surgeons of England.

A FRUIT.

By Dr. Robert Brown, F.L.S., etc.

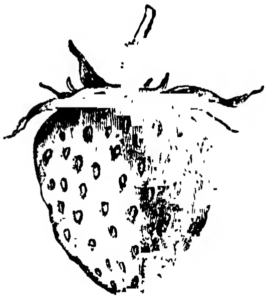

Fig. 1.—Strawberry, with hard Fruits on the surface of the swollen top of the Fruit-stalk.

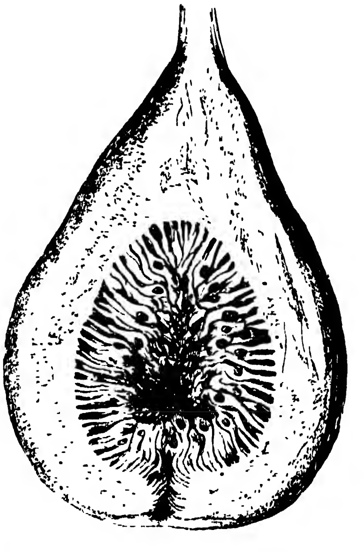

Fig. 2.—Longitudinal Section of Fig, showing Fruits in the centre of the enlarged and hollowed Fruit-stalk.

WHAT is a fruit? To answer the question would seem at first sight not to require any botanical knowledge whatever. “It is simply the juicy organ, like an apple, strawberry, or peach, which remains after the flower disappears.” This definition—or any other framed on the same lines—will not suffice for the botanist. To him a fruit is not necessarily edible, and, indeed, the most familiar of so-called “fruits” he knows are, botanically, not fruits at all. For instance, the fleshy parts of a pear or an apple are strictly only enlargements of the calyx, and of the top of the flower-stalk (peduncle), the real fruit being the “core” in the middle; while the true fruits of the strawberry (Fig. 1) are the little hard seed-like bodies which dot the surface of the juicy edible portion, which is also only an enlargement of the top of the peduncle. Again, the fig (Fig. 2) has its real fruits inside the more prominent outer portion, which consists simply of the expanded and hollowed-out top of the stalk, containing within it the seed-like fruits. In the “hip” of the dog-rose, the fruits are the seed-like bodies inside the soft edible outer covering, which is also an expansion of the fruit-stalk. It thus appears that, according to the botanist, a fruit need not be edible, or even soft, but simply the mature pistil including the ovary,* containing inside it the seed or seeds, which are, again, the ovules fertilised by contact with the pollen. There are, however, exceptional cases in which the fruit is ripened although the seeds are abortive. A very familiar instance of this is afforded by the Corinth grapes from which Corinths or “currants” are made, the Muscatel grapes, and the St. Michael oranges, all of which are diminutive and almost “stoneless.” In other words, the seeds inside these fruits are in the form of ovules. Nor is it universally the case that the fruit matures in the air. The ground nut (*Arachis hypogæa*), the allied genus *Voandzeia* of Surinam, and a species of the clover genus (*Trifolium subterraneum*), after their ovules have been fertilised, bury themselves in the ground, and if anything interferes to prevent this, the fruit withers away and dies without ripening. The fruit being, therefore, only the matured pistil—or practically the matured ovary—a description of the one applies with modifications to the other also. Like the pistil, it is made up of one carpel or of several coalesced, or of a number of carpels separated one from the other.

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* “A Primrose;” “Science for All,” Vol. II., p. 219.

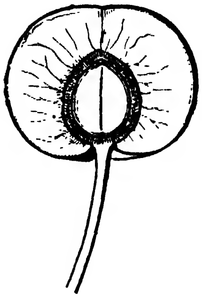

Fig 3.—Longitudinal Section of a Cherry, showing the three coats of the fruit-wall (the outer skin, the middle fleshy coat, and the inner one, or "stone"), with the seed in the centre.

The parts of the ovary, however, get altered in the process of ripening, until it is sometimes difficult to detect them in the fruit. Take, for example, the cherry (Fig. 3), peach, plum, or any other stone fruit. Here we see the walls of the ovary have become swollen, and in the process of maturation developed the sugar, juices, and fine flavours which give these fruits their edible value. There are, in reality, in, let us say, a peach, three coats. The outer one is the skin which surrounds every part of a plant, the surface of the stigma excepted; the middle is the pulpy or fleshy layer; while the innermost is hard and woody, and constitutes the "stone." Inside this stone is the seed itself. Now all these parts can be traced in any true fruit, though sometimes, as in the case of a grain of wheat, which is a fruit, the walls are so excessively thin, that the seed to which this covering is firmly attached is the most prominent and valuable part of the structure. Take, again, the pod of a pea. In this fruit we have the outer skin and the middle fleshy coat, while the inner layer which lines the pod is not, as in the stone fruits, marked by the deposition of "lignine" in its cells, but is a thin parchment-like membrane. There are, however, exceptional cases in which the middle layer of the fruit does not constitute the pulpy portion. For instance, in the mulberry, rose, and apple, the edible part is formed by the calyx and fruit-stalk, either alone or conjoined with the ovary. Again, in the juniper and yew the scales become fleshy, and constitute the "berries" of these trees and shrubs, though these juicy scales do not, as in the yew, always cover the seed, the point of which protrudes through the end of the rosy fruit-covering. Such a fruit is, however, no fruit at all, for a fruit can only be constituted by the wall of the ovary, and, in the order of plants to which the firs, pines, yews, and cypresses belong, the walls of the ovary are wanting, and the modifications of scales referred to are employed to cover the naked seeds. In the almond, the middle coat is not fleshy as in the peach, but of a thin, almost leathery, consistence. However, in the variety called the peach-almond the stone is covered, not by the "husk," but by a pulpy flesh which is edible.

As a rule, the calyx and corolla disappear after the pollen has fallen on the stigma and fertilised the ovules, and the life of the plant has become concentrated in these immature seeds. Then, also, the style and the stigma, when the former is wanting, also fade, though in one or two cases they remain attached to the fruit in a shrivelled condition, and in some plants, like the clematis, the anemones, and the herb-bennet (*Geum urbanum*), they even take a new development, and become a marked addition to the fruit. In the clematis, or traveller's joy, for example, the styles take the shape of the long feathery awns which have given the common species (*Clematis vitalba*) of our hedges the popular name of "old man's beard." In the strawberry and geum, among other plants, the calyx remains after the fruit has ripened, and in the former plant is familiar in the form of the ruff-like circlet of little leaflets which surround the base of the so-called fruit. In the apple and pear the calyx may be seen in the end opposite the stalk in a more or less shrivelled-up condition, and, indeed, as we have already explained, may be considered as forming, by the expansion of its tube, or by the expansion of the stalk of the flower on which it is situated, the fleshy portion of the fruit. In the raspberry (Fig. 4) and the mulberry (Fig. 5) the fruits look very much the same. But a short examination will show how different they are, for while in the former the calyx remains quite distinct from the fruit, in the latter it gets united with each of the little fruits and forms part of it. In the *Gaultheria*, the berries of one species of which are so familiar to every traveller in North-west America as the "Salal," the calyx becomes, to all appearance, a part of the fruit. Carefully watching the progress of growth, and dissecting the parts instead of eating them, the real fruit will be found to be a dry pod within the prominent outer one. Another false fruit is the

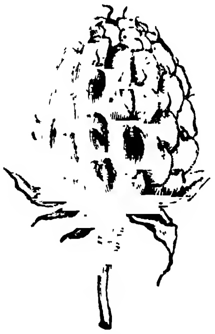

Fig. 4.—Raspberry.

so-called winter cherry, which forms such a familiar ornament of dinner-tables. It is, of course, no connection of the cherry, being much more nearly allied to the potato, the tobacco plant, the cayenne pepper shrub, and the thorn-apple, the only ground for its popular name being the round, cherry-like fruit which gives it its value as an ornamental shrublet. However, this "indusium," as it is called, is not really a fruit proper, in so far that the cherry-coloured covering is simply a fleshy calyx concealing the humble fruit within. In other "fruits," so called—the *Hovenia dulcis* of Japan, for example—the portions eaten under that name are only the swollen peduncles, the edible portions thus having even less claim than the strawberry and apple to the botanical designation which they usurp. Finally, in the pine-apple, the fruit is even more complex, for it is a union of a great number of fruits, in which the seeds are abortive, combined with the bracts, or leaf-like organs sometimes found beneath the flower.

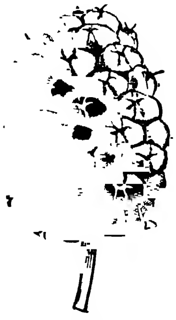
Fig. 5.—Mulberry.

These and other modes of forming real or simulated fruits have given rise to a great number of forms, which have been characterised by names, sometimes useful, still more rarely necessary, and most frequently perfectly superfluous. For instance, there are among the dry fruits *nuts* like the acorns, and *achenes* like the fruits of buttercups (Fig. 6), and the so-called "seeds" of grasses ("caryopsis," as sometimes called), and the ordinary cereals, most of which are only different species of grasses. Then there are *follicles*, as in the hellebore and aconite (Figs. 7 and 8); *legumes*, as in beans and peas (Fig. 10); *siliquas* (Fig. 9), as in the wall-flower, turnip, and plants of that order; and *capsules* (Figs. 11, 12), as in the poppy, tulip, rhododendron. Finally, not to multiply the long array of names, there are among the succulent fruits *drupes*, as in plums, cherries (Fig. 3), and peaches; and *berries*, as in grapes, oranges (Fig. 13), and gooseberries. But any classification of fruits yet formed is purely artificial, and only serves the purpose of artificial classification—viz., as an aid to the memory and an index by which the stores of real knowledge may be got at.

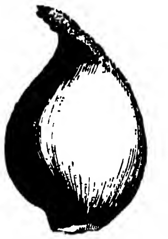
Fig. 6.—Achene of the Buttercup.

A much more interesting inquiry is that which concerns the changes which the ovary undergoes during the period at which it is arriving at maturity, or, in more familiar language, ripening. Here, again, the reader must be reminded that a fruit is only an adult ovary, and that, theoretically at all events, its structure ought to be the same as that of the organ of which it is the complete development. As a rule, during the period which begins after the ovules have become fertilised, the wall becomes sappier and more swollen, and the materials within considerably enlarged, though the dry, membranous pod of the bladder senna is quite as much a fruit in the botanist's eyes as the luscious guava, and perhaps even more so than the monstrous Duchesse pear, one of which commands in the London market about as much as a labourer can for a week's work. The skin of the fruit is, of course, the epidermis, of which we have already had enough to say (Vol. I., p. 20), and in nearly every respect agrees with that thin covering as found on the leaf. It has stomata and chlorophyll, and in all respects performs the functions of the epidermis, though in some fruits the glossy appearance of the skin is due to the deposition of a delicate layer of wax in its cells, while the colour of, say, a "rosy-cheeked apple" is caused by some alterations in the chlorophyll of much the same nature as those which take place in leaves when they assume their golden-yellow and russet-brown. Again, as we have seen, the walls of the ovary, which in an early stage of the plant's life were comparatively juicy, may become rapidly hard and dry, owing to the loss of the sap, though, in the case of most edible fruits, the contrary operation is undergone; or the outer portion of the ovary wall remains soft and pulpy, while, as in the case of stone-fruit, the inner one, originally soft, becomes hard and stone-like. The way the fleshy parts of edible fruits increase in amount is by the cellular tissue (Vol. I., p. 295), which is the component

Fig. 7.—Separate Carpel of Aconite, showing a single Follicle.

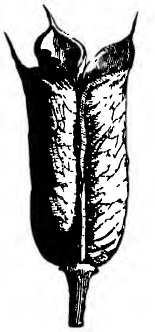
Fig. 8.—Fruit of the Aconite, composed of three Carpels cles).

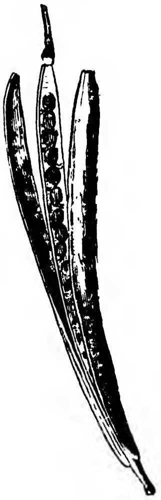
Fig. 9—Siliqua of the Wallflower.

material of the soft parts of every plant or organ of the plant, receiving, under the stimulus of light and warmth, a tendency to rapidly develop, by the addition of one little bladder-like cell to another, until the mass of pulpy material—such as can be seen in an orange—gets enlarged. At the same time, the woody fibres, which were originally contained in this part of the fruit coat, get attenuated, partially absorbed, and lost in the midst of the mass of soft matter. The extent to which this is the case is important if the fruit is to be eaten, and, accordingly, low-class pears are frequently said to be woody, a term which needs no explanation. There is, indeed, always a tendency in nature to revert to the wild type. The aim of the gardener may be described as a desire to produce cellular tissue in preference to woody fibre, and the more of the one and the less of the others there is the more succulent will be the pot-herb or the fruit. Yet in cutting across a pear the reader must often have felt the edge of the knife grate against some hard particles in the midst of the soft "flesh." These gritty specks were cells which had displayed an inclination to retrograde, by accumulating in their interior, not sugary sap and fragrant ethers, but "lignine," such as that which makes the once soft inner layer of the ovary wall of the peach hard as stone.

Fig.10.—Legume of the Pea.

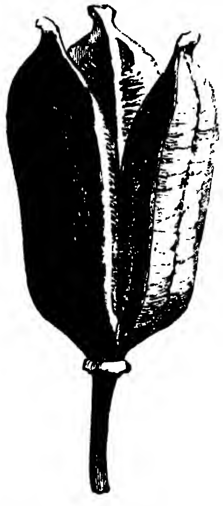

Fig. 11.—Capsule of the Tulip, composed of three Carpels.

But there are during the process of ripening chemical changes going on quite as important as the physical ones to which we have alluded. An unripe apple is, for example, sour; a ripe one sweet. One pear is, again, of the most delicious flavour; another is tasteless and unpalatable. Finally, to keep to the same series of examples, a crab-apple from the hedgerow is so acid that it "draws the mouth together;" while a Normandy pippin is so sugary that it seems scarcely allied to the first-named fruit. All these differences are due, first, to cultivation, and, secondly, to the changes which go on in the walls of the ovary during the process of ripening. Briefly, these changes may be characterised by saying that the amount of sugar contained in the cells becomes greater, while the acids, starch, and tannin proportionately diminish. These facts may be guessed at by the rough analysis of the tongue.

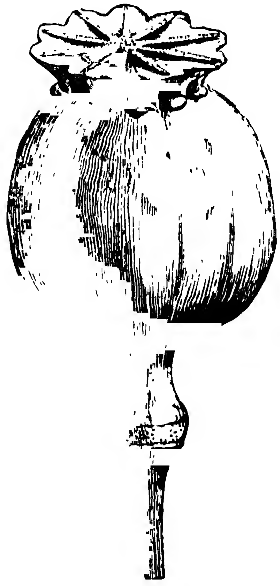

Fig. 12.—Capsule of the Poppy.

A green fruit acts like a leaf: under the action of the sun it gives out oxygen. But when ripe, the respiratory function alters, in so far that carbonic acid gas (carbon dioxide of the modern chemist), is exhaled, while oxygen is absorbed. In chemical composition fruits at an early age agree very closely with leaves, just as we have seen that their structure and functions are very much the same. This is, however, in the earliest stages of their growth. By-and-by they become sour from the production within their cells of tartaric acid (as in grapes), citric (as in lemons, oranges, and cranberries), malic (as in apples, gooseberries), &c., and at this period give out little, if any, oxygen. But in time a change takes place. Tannin and these acids disappear, or become much reduced in quantity, while, as the ripening goes on, sugar becomes notably increased in amount. At the

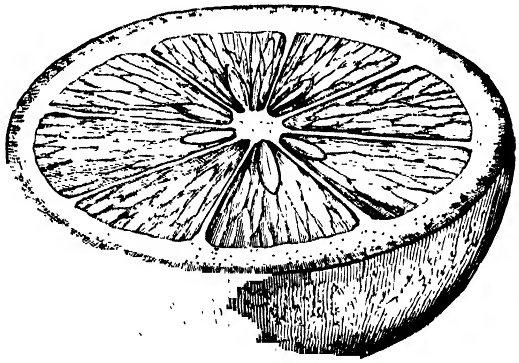

Fig. 13.—Transverse Section of an Orange, showing the form of Berry sometimes called Hesperidium.

same time, the fibrous and cellular tissues diminish, the sugar being, to some extent, owing to chemical transformation, produced at their expense. The gummy, mucilaginous, and gelatinous matters are also capable of being converted into sugar. Thus, if apple jelly—that is, the pure jelly of the fruit—be treated with a vegetable acid, and dissolved in water, a sugar much like that in grapes is obtained. But though this is the regular rule, there are some curious disparities in carrying it out. For instance, in apricots and pears, malic acid keeps diminishing as the fruit ripens, while in currants, cherries, plums, and peaches that acid augments during the same period. Again, in currants, cherries, plums, and pears gum keeps diminishing; while in apricots and peaches it augments, and so on.

And here it may be useful to glance at the changes which take place in green fruits during the operation of cooking, for the application of artificial heat exercises much the same influence upon them as the more moderate influence of sun and light. That is, the acids and mucilaginous products, reacting on one another by the aid of heat, are converted into sugar.

Bassorin, salep, and pectine are all modifications of vegetable jelly, and along with sugar there is produced during the process of cooking a similar jelly in fruits, which has nearly the properties of starch when this has been altered by hot water. When dry, it is horny or cartilaginous, and when moist it swells up, becomes gelatinous, and can be dissolved in cold water. Finally, it might be added that in some fruits the sugar is liquid; in others, as for example the grape, fig, and peach, partly concrete; and that in a third series, notoriously that to which the olive belongs, oils accumulate during the process of ripening. To sum up, it might be said in general terms that the production of sugar keeps pace with the ripening of fruits. But when succulent fruits are mature, the sugar in its turn undergoes a process of oxidation, or chemical burning up, which induces a series of changes, which finally culminate in the rotting of the fruit.

The fruit during the process of ripening requires, like the flower, a large amount of sap to support it.* Hence a plant which begins to flower and fruit early rarely produces large fruits, and is sometimes killed after the first efforts have exhausted the strength of its constitution. Gardeners, being aware from experience of this peculiarity in vegetable physiology, nip the flower-buds of rare fruit-trees, until they have acquired sufficient vigour to bear the strain of fruiting, and when they wish a tree to produce large and juicy fruits they prune it of all superfluous wood which might use up the nourishment required for the support of the flowers and fruit. It may also be remarked that the fruits of young St. Michael orange-trees are often fully seeded. It is only when the tree is getting old and feeble that the seed ceases to be matured, and the fruit, accordingly, to be valued for that very reason. When the fruit is sufficiently ripe, it falls, owing to the gradual contraction and final snapping of the stalk by which it is attached to the tree- -just what we have seen happens in the case of the leaf, for then no further sap is required for its support.

But, as we shall see by-and-by, many fruits open in various curious ways in order to liberate the seeds, which though considered apart from it, are, of course, part and parcel of the fruit, and by far the most important part also. Accordingly, either immediately before the fruit falls, or soon after this event takes place, the "dehiscence" of the fruit enables the seeds to enter the ground, and thus perform their function in the economy of the plant. But there are numerous fruits which are "indehiscent"—that is to say, they do not open. Among these are the greater number of edible ones, such as apples, pears, berries, and stone fruits. In these cases the fruits fall to the ground when they are ripe, and in due time rot, and thus permit the seeds to escape into their destined element. Before, however, the process of putrefaction sets in, or rather immediately after the oxidation, which is its first stage, has begun, the fruit is "bletted."* This "bletting" is the intermediate stage between maturity and decay, and is that yellowish woolliness of the fruit familiarly known as "mellowness." When the fruit is fully ripe the materials within it are as complete as they ever will be, and the cell contents have become tolerably equalised. The water in the fruit has grown less and less, owing to less and less being absorbed as maturation has proceeded; and, in brief, everything is so perfect that the only change must be retrogression, for no organised being ever remains perfectly still. This overthrow of the balance of nature is accomplished by bletting, which may be concisely explained in the words of the famous Genevan botanist, M. Alphonse de Candolle:—"After the period which is generally called that of ripeness, most fleshy fruits undergo a new kind of alteration—their flesh either rots or *blets.* These two states of decomposition cannot, according to Bérard, take place except by the action of the oxygen of the air, although he admits that a very small quantity is sufficient to cause it. He succeeded in preserving for several months, with little alteration, the fleshy fruits which were the subject of experiment (apricots, currants, cherries, greengages, peaches, pears), by placing them in hydrogen or nitrogen gases. All fruits at this extreme period of their duration, whether they decay or whether they blet, form carbonic acid with their own carbon and the oxygen of the air, and moreover, disengage from their proper substance a certain quantity of the carbonic acid. Bletting is, in particular, a special alteration. This condition is not well characterised in any other fruits than those of Ebenaceæ [Ebony order, to which belong the *Diospyros*, or 'persimmon,' of the United States] and the Pomaceæ [or apple order]. Both these natural orders agree in their fruits being austerely sour before ripening. It would even seem, from the fruits of the persimmon, the sorb, and the medlar, that the more austere a fruit is, the more it is capable of bletting regularly." Indeed, a medlar only becomes edible after having undergone the process of bletting. At first it is sour and astringent, but during its bletting it loses its acid and tannin. It has been found that a Jargonelle pear in passing to this state loses a great deal of water (83·88 reduced to 62·73), a good deal of sugar (11·52 reduced to 8·77), and a little lignine (2·19 reduced to 1·85), but acquires rather more malic acid and gummy matter. Lignine, in particular, seems in this kind of alteration to undergo a change analogous to that of wood in decay. The practical deduction from this is that if fruits are kept in closed vessels, in an atmosphere free from oxygen, they will preserve for a much longer period than they otherwise would. A simple process is said to consist in "placing at the bottom of a bottle a paste formed of lime, sulphate of iron, and water, and afterwards introducing the fruit, it having been pulled a few days before it could have been ripe. Such fruits are to be kept from the bottom of the bottle, and as much as possible from each other; and the bottle is to be closed by a cork and cement." The fruits are thus placed in an atmosphere free from oxygen, and may be preserved for a period varying with their nature. For instance, Dr. Lindley, whose description has been quoted, notes that peaches, prunes, and apricots have by this method been kept good for from twenty days to a month, and pears and apples for three months. If they are withdrawn after this time, and exposed to the air, they ripen well; but if the times mentioned are much exceeded they undergo a particular alteration, and will not ripen at all. This leads us to remark that apples, pears, cherries, gooseberries, currants, and the like continue to live after being taken from the trees and bushes, for it has been shown that they absorb and exhale carbonic acid gas, and ripen. But, if we are to adopt, in a question on which there are several views, those of M. Pasteur, in time, the fruits being prevented from absorbing oxygen, they begin to assimilate it from their own tissues, an alcoholic fermentation commences, and the fruit becomes soft and pulpy. In short, it *rots.* Fruits also may, by being covered with wax, be prevented for a time from putrefying. If the apples are very acid, they may, being exposed to light and air, become sweeter, and *vice versa.* In selecting wild fruits for cultivation sour varieties should be selected, for it is the propensity of cultivation to develop sugar, and to render fruits at all well-flavoured a certain dash of acidity is requisite.

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* "Flowering:" "Science for All," Vol. III., p. 26.

* This is a convenient word, Anglicised by the late Prof. Lindley from the French *blessé*, a word signifying that bruised appearance we see in some fruits.

How long does a fruit take to ripen? In the case of a grass, it takes only a few days; and in some Compositæ, like dandelions, the process of maturation seems about equally rapid. But even grasses vary among themselves as to the period required for ripening their fruits, or, as they are called commonly, "seeds." In some, such as the fescue grass, the common quake grass (*Briza media*), the wild oat, &c., from thirteen to seventeen days, according to the season, are requisite; while the bent (*Elymus arenarius*), &c., take from forty to fifty-seven days. Many of the Coniferæ (fir, pine, and cypress order) take more than a year; the mistletoe takes nine months, and the majority of the fruits of temperate climates occupy from three to six months in bringing the ovary from the period when the ovules are fertilised to the condition of maturity known as the ripe fruit.

A fruit we have hitherto considered mainly as a fruit-wall, the materials which this wall encloses being, for convenience' sake, left out of account. It is, however, needless to say that the seeds are part of the fruit, and after all, so far as their botanical importance is concerned, the most important part of it. The various modes in which the fruit opens—when it does open—the nature of the seed, its sprouting, and the modes which are adopted in nature to permit of its being scattered over the world, are all extremely interesting, but may be best discussed by themselves.

COOLING.

By William Durham, F.R.S.E.

THAT a body may be made hot, and by being exposed to air of a lower temperature than the medium through which it was warmed, be again cooled, is of course a very familiar fact to every one.* The nature of this operation, both from a scientific and a practical point of view, is, however, of no small interest.

There are two ways in which a body may cool. It may radiate its heat away into space just as, for instance, a kettle of boiling water placed in the middle of a room loses its heat by radiation, or it may part with its heat to some other body which is actually in contact with it; thus, if we put our hands into cold water, we are conscious that they are losing heat which is passing into the water; if, on the other hand, we put them into hot water, we are conscious of receiving heat which the water is losing. Generally speaking, both phenomena are exhibited in the cooling of any body. Thus, in the case of the kettle, before the heat radiates from its surface it has to pass from the water through the metal of the kettle, where we have the heat passing from one body to another in contact with it. Now, when heat passes through a body in this way, we say the heat is conducted through it. Thus, in the case before us, the heat is conducted from the inside of the kettle through the metal to the outside, and is there radiated away. The capacity, then, of any body of allowing heat to pass through it in this manner is called its "conductivity." The following experiment will throw light on the preceding remarks:—An earthenware teapot was filled with water at 120° Fahr., and placed on the centre of the table. The temperature of the room was 58°. After standing one hour the temperature of the water had fallen 32°—that is, as much heat had been conducted through the earthenware, and radiated into space, as would have raised the water in the pot 32°. The teapot was now emptied, and refilled with water at 120°, as before, but this time after being placed on the table, it was covered by a "tea-cosy." After standing one hour its temperature was found to have fallen only 16°, or one-half of the amount of the former experiment. Now we see by this experiment that the "cosy" reduces the outflow of heat; it does not allow so much to pass through it as passed through the earthenware teapot alone. We might vary this experiment, and instead of a hot body use a cold one—say a piece of ice. If we placed the ice in the room, and noted how long it took to melt when uncovered, and then how long it took to melt when covered with the "cosy," we should find the time much longer in the latter case than in the former; and as we know ice melts by absorbing heat, we should understand that the ice took longer to melt when under the "cosy" because the "cosy" did not allow the heat of the room to pass rapidly through, but reduced the supply which the ice could receive. The "cosy," then, may be looked upon as a sort of damper, stopping, to a considerable extent, the flow of heat in either direction, just as we put down a sluice-gate to reduce the flow of water in a mill lade; and we express this fact by saying it is a bad conductor of heat, or that its conductivity is small.

If we made covers for our teapot of various substances we should find a great difference in their conductivities. Some would conduct the heat away rapidly, and others slowly, like the "cosy."

This fact, that conductivity for heat varies in different substances, has long been taken advantage of by man, although he has paid little heed to the scientific view of the question. Thus our bodies, for instance, being kept at a temperature above that of the surrounding air, radiate heat away, and would rapidly cool were it not for the constant renewal of the supply by the oxidation or burning of food in the system. Experience, however, very soon taught man that to allow the radiation to go on without any check might result in serious consequences; therefore he adopted the plan of reducing the cooling process by covering himself with some bad conducting material, such as the skins of animals, and, as his knowledge and experience grew, with woven woollen garments; in fact, he put a "cosy" over his naked body, with very comfortable results, as we all know. Nature does for the lower animals what man does for himself, and covers them with bad conductors, such as hair, wool, &c. It is rather instructive, by the way, to note that the animal which is gifted with sufficient intelligence is left in this matter to shift for himself, and with the best results, as the needs of the body stimulate the mental faculties in a remarkable manner.

It is not, however, in clothing alone that the importance of the study of conductivity appears, but also in our manufactures, where inattention to its principles may cause the loss of hundreds, or even thousands of pounds every year. Thus, consider the steam-boilers in use all over the country in such countless numbers. Every one of them is, in principle, exactly the same as the teapot filled with hot water, and will radiate away heat from its surface very rapidly unless means be taken to check this. If we take our simple and rude experiment as even an approximation to what occurs with boilers, we see what a serious matter it is. Consider the quantity of water contained in these boilers, and that every hour they may radiate heat so as to lower the temperature of the water 32°, and let us calculate the amount of energy or power of doing work that may be lost in this way. Suppose the teapot contains one pound of water, and that it loses 32° of heat in one hour. Now, it has been shown that the amount of heat required to raise one pound of ice-cold water one degree is equivalent in mechanical energy to raising 772 lbs. weight through the space of one foot. It is near enough to the mark, then, to say that the hot water in the teapot has lost in one hour as much mechanical energy as would raise $772 \times 32 = 24{,}704$ lbs. one foot. Now a ton of water in precisely similar conditions would lose as much heat as would raise 24,704 tons one foot high. This shows the enormous amount of waste that may go on; for, of course, loss of mechanical energy means waste of fuel. A knowledge, then, of the laws of conductivity, and of cooling generally, is of the utmost importance in an economical point of view.

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* "Getting Warm:" "Science for All," Vol. III., p. 263.

Hitherto we have considered how to keep a body from cooling too rapidly, but it sometimes happens that we wish to cool some substance as rapidly as possible, and here again a knowledge of the laws of conductivity renders inestimable assistance. Of all substances the metals are generally the best conductors of heat; the metallic part of a hot-water kettle we may not be able to touch, while the bone or ivory handle may be quite cool. When we touch metal either much hotter or much colder than ourselves, we quickly feel the result, and get more readily burnt or chilled than when we touch, say, a woollen cloth at the same temperature. We may easily prove this by putting a piece of iron and a woollen cloth in the open air on a cold winter day, and after they have been reduced to the same temperature as the air, touch both: the iron will feel much colder. The reason of this is that the iron conducts the heat of the hand most rapidly away, and we feel the chill quickly in consequence; while the woollen cloth, being a bad conductor, does not allow the heat of the hand to penetrate it so quickly, and consequently we do not feel the sudden chill. If we wish, therefore, to cool a body rapidly we may give it a metallic cover. Thus (Fig. 1), if we make a spiral of stout copper or iron wire about half an inch in diameter, and put it over the flame of a candle like an extinguisher, the flame will be extinguished, because the copper, by its great conductivity, cools it so rapidly that the temperature falls below the igniting point. A valuable application of this principle is found in the Davy lamp. The danger in coal-mines from the explosion of fire-damp, as it is called, would be entirely obviated if the temperature of the mixture of air and fire-damp could be kept below the igniting point; but the miners must have lighted lamps in order to see to work, and where these lamps burn the mixture will be raised to the point of ignition. Now let us take notice of the lighting of an ordinary gas-burner when the gas is turned on. We take a blazing match or paper and light it, but it will not light if the match is not in flame, nor will it light if we apply a metallic wire at a low red heat, which is not sufficient to raise the mixture of gases to the igniting point. Now Davy merely surrounded the flame of the lighted lamp with metallic wire, which conducted and radiated away the heat of the flame so rapidly that it was never hot enough to raise the mixture of gases outside of it to the point of ignition; it was, in fact, putting a cooling "cosy" over the lighted lamps, and yet allowing sufficient light to get through. A very simple experiment will illustrate the principle of the lamp. Take (Fig. 2) a piece of copper wire gauze three or four inches square, hold it one or two inches above a gas-burner, then turn on the gas and apply a light above the wire, when the gas will be immediately lighted there, but the flame will not pass through and light the gas at the burner. The rapidity with which metal conducts heat away may be very well shown by wrapping a handkerchief very tightly and evenly round a

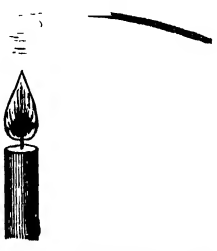
Fig. 1.—Showing the Conductivity of Copper.

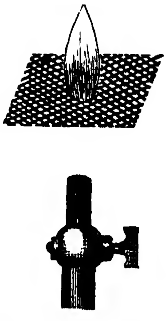
Fig. 2.—Illustrating the Principle of the Davy Safety Lamp.

polished ball of metal and holding it in the flame of a candle; the handkerchief will not be burnt for a considerable time, as the metal takes the heat from it so rapidly that it does not readily rise in temperature to the point of ignition. If, however, we repeat the experiment, substituting a wooden ball for the metallic one, the handkerchief will be burnt directly.

Having thus generally considered conductivity and its action on cooling, we shall now describe the manner in which its laws are studied, which will enable us to understand its nature more thoroughly. In the article we referred to at the commencement of this paper there is a general method described of testing conductivities, and a very simple experiment, which any one may perform, will illustrate this. Take a bar or strip of copper and a similar one of iron, place them end to end, supported as in Fig. 3, stick a little bit of candle on each at the same distance from the end, apply heat by a lamp, and note from which bar the bit of candle drops first, and the time each takes before the candle drops will give some notion of their relative conductivities. The copper will be found much the better conductor.

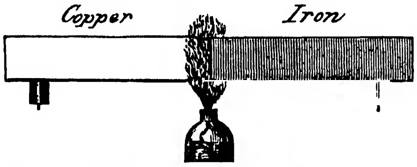

Fig. 3.—A Method of Testing the Conductivities of Metals.

In this and in all similar experiments, however, we demonstrate rather the conduction of temperature than of heat. A little consideration will convince us of this. It has been shown (Vol. III., p. 269) that all bodies do not require the same *quantity* of heat to raise them to the same *temperature;* water, for instance, requiring about thirty times as much as mercury. Now, in the experiments with the metal strips or rods, although the temperature travelled faster along the copper than along the iron, we do not know from the experiment whether this might not arise from the copper requiring less heat than the iron to raise it to the temperature at which the wax of the candle melted. An analogy may help us to understand this. Suppose two pipes of equal length bent upwards as a syphon, one double the diameter of the other, and we poured water at the same rate into each, the water in the smaller one would rise much more rapidly than the water in the larger. Now the height of the water in the pipes might represent the temperature, while the quantity of water would represent the quantity of heat passing through the pipes, so that when both pipes were filled, although the height to which the water rose would be the same in both, the *quantity* would be much greater in the larger one.

Although these experiments, in a general way, give us an approximation to relative conductivities, we want some more precise information. We must have, in the first instance, a standard unit of heat to measure by, just as we have our standard pound weight by which to weigh. The standard adopted is that amount of heat which will raise one pound of ice-cold water 1°. Now in ascertaining the conducting power of any substance, we want to know how many of these units of heat it will allow to pass or flow, say, through one square inch in one minute. In this way we can compare the conductivities of various metals and other bodies, just as, for instance, our tea-cosy allowed sixteen such units to pass through it in one hour, and we should know its conductivity by dividing this by the square inches on its surface, and by sixty to reduce the time to minutes, supposing the conduction to be regular. As we require to measure conductivity at high temperatures, water would not be suitable as a source of heat, so the following arrangement is adopted. A long bar of metal is taken (Fig. 4), A B. The end A is heated by means of a furnace or bath of molten metal, just like a poker thrust into the fire. Of course it soon gets hot by conduction, being hottest at A, and gradually cooler towards B, which is at the temperature of the room. Thermometers are inserted in little holes, *a*, *b*, *c*, *d*, *e*, drilled in the bar at regular intervals from A to B. That at A, of course, indicates a higher temperature than that at B, and there is a regular gradation between the two, and after a little time the temperature of the various thermometers gets steady and invariable, and a line joining all forms a curve something like that shown in the figure. Now, it is evident that there must be a regular flow of heat along the bar from A to B, because the bar is continually losing heat by radiation into the room, and yet its temperature remains steady, and if we can measure the quantity of heat which is being radiated from the bar we know how much heat is flowing along, just as, for instance, we know the quantity of water that is flowing through a pipe kept always full, if we measure the quantity that the pipe is discharging at its outlet. Further, we know this amount of flow is between the temperature of A—say it was 300°—and the temperature of B—say

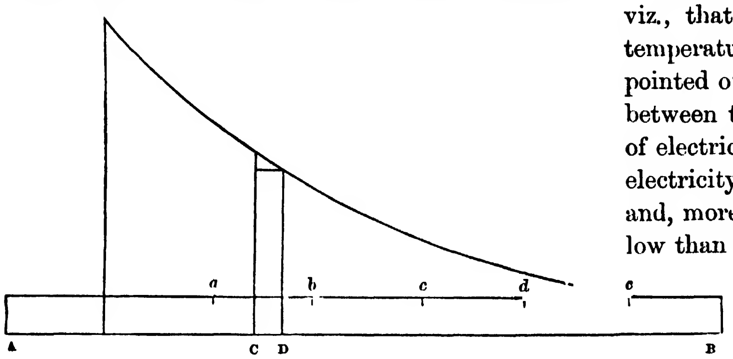

Fig. 4.—Method of Testing Conductivities at High Temperatures.

at 60°, or a difference of 240°. This would be analogous, again, to the flow of water at a certain rate when the head of supply was a certain number of feet above the outlet. There is one important difference, however, between the flow of water in a pipe and the flow of heat on the bar; the water discharges itself only at the outlet at the end of its length, while the heat is discharged at every part of the length of the bar, so that to get at the quantity of heat we must study the radiation at all parts. We therefore examine it in parts, say an inch of its length between C and D; the curve gives us the difference in temperature, and we have to find out how much heat is radiated at this temperature in one minute. To ascertain this, a small bar of the same material is heated up to the highest temperature indicated at A, and then allowed to cool, and the rate at which it cools is carefully noted at regular intervals of, say, one minute. Knowing, then, the capacity for heat of the substance under experiment, we know the quantity of heat it loses as it sinks 1° in temperature, and from this and the heat curve on the larger bar we can readily calculate the conductivity at the various temperatures of the experiment. From experiments conducted in this manner the conductivity of the various metals was very accurately determined, and placing silver, which is the best conductor of heat, at the head of the list, the following represented the conductivities of the metals :—

Silver	100·0	Iron	11·9
Copper	73·6	Lead	8·5
Gold	53·2	Platinum	8·4
Tin	14·5	Bismuth	1·8

We see from this that the range is very considerable, silver being about sixty times better than bismuth as a conductor of heat. The list also shows us the necessity of experimenting in this rather than in the simple manner already described, because, if we take iron and bismuth, we should find that *temperature* travels faster along the latter, while we see from the table that the former conducts the greater quantity of heat.

These experiments brought out another fact, viz., that metals conduct heat better at a low temperature than at a high one. It was soon pointed out that there was a remarkable similarity between the conduction of heat and the conduction of electricity. The order in which metals conduct electricity is very much the same as that for heat, and, moreover, metals conduct electricity better at low than high temperatures. Professor Tait, however, has shown that it is only in some metals that the conductivity for heat is lessened by increase of temperature. This is rather surprising and unexpected.

Owing to the setting up of currents by heat, it is not easy to measure the conductivity of liquids and gases; indeed, so far as gases are concerned, next to nothing is known as to their conductivities.

That water is a bad conductor may be shown by filling a jar with water and placing a "differential thermometer" within it, then on the top a vessel of boiling water or oil. The heat from this will penetrate very slowly into the water beneath, so that it will be long before the thermometer will be affected.

Among solid bodies the worst conductors are powders, from their want of continuity; sawdust, for instance, being a very bad conductor, also wool, feathers, &c. This, possibly, arises in great part from the air which these bodies retain; the heat has to pass from the substance to air and from air to the substance many times, and, as air is an exceedingly bad conductor of heat, this greatly retards its flow. This is somewhat the same action as obtains with double doors and windows; the air retained by these arrangements acts as a barrier to the escape of heat. Rocks, stones, &c., are bad conductors of heat, and some crystals conduct it better in one direction than another. In fibrous substances, also, such as wood, the conduction varies with the direction of the fibres.

In considering these various phenomena, we observe that, as a rule, closeness and uniformity of texture seem to be allied with good conducting capacity, and this is quite in keeping with what we should expect, since we know that heat is a vibratory motion communicated from one particle of matter to another, and we can understand how the vibration passes more easily when all the particles are of one kind and in close proximity.

The effects of radiation on the cooling of any body have been sufficiently dwelt on;* but it may, perhaps, be mentioned that a body at a high temperature cools by radiation more rapidly than one at a low temperature; thus a kettle of water at 212° will lose more heat in a given time than one at 100°. The difference between 212° and the temperature of the room being much more than that of 100°, there is, as it were, greater pressure urging the heat away.

There is an interesting application of the laws of conduction and cooling to the question of the age of the world. As is well known, geology has proved the world to be of immense age, but hitherto has not been able to fix any definite limit to that age. Sir William Thomson has attempted to solve this problem, and although his conclusions have by no means been generally accepted, yet they are interesting as pointing out a method by which, as knowledge increases, we may get the desired information. There is little doubt that the earth is a cooling body, and that in the ages past its temperature must have been much higher than it is at present. The reasons for this conclusion have already been pointed out in this work (Vol. II., p. 111). The question, then, is, can we, from our knowledge of the laws of conductivity, of heat, and of cooling, say how many years have passed since it was in a molten state, and when its outside crust was first formed?

Let us consider our homely illustration of the tea-pot filled with hot water; suppose we found it to lose 32° in the first hour, 24° in the second hour, and 18° in the third, and further, that we knew the water was boiling, or at 212°, when first exposed to cooling, and on examining it we found its temperature to be 156°, we would know it had been cooling for two hours, or if it were 138°, that it had stood three hours. Now, this is just the principle we apply in studying the cooling of the earth; but as the earth is a solid body formed of various materials, the problem is much more complex. Were we, instead of our tea-pot, to take an iron ball and heat it thoroughly up to a red heat, and then let it cool, we should find after the lapse of some time that the centre would still be at a red heat, while the outside would be black and comparatively cool, and the temperature would regularly increase as we penetrated inwards, and, as in the case of the metallic bars of our experiments on conductivity, we might represent this increase of temperature by a curve. Now, as we know how much heat it takes to raise iron to a red heat, and also how much heat will flow through iron from the inside to the outside, and be radiated into space in a given time, we are in a position to calculate at any given time how long it is since the whole ball was at a red heat. The condition of this experiment approaches more nearly that of the earth as a cooling body, but it is still vastly simpler, as the material is all of one kind, and its capacity for heat and conductivity can be readily studied and measured, while the earth is such a complex body, its different parts having different capacities for heat, &c., and moreover, we cannot get at its interior parts at all, so as to know their composition, temperature, &c. The difficulty of the problem is thus very apparent, and every allowance must therefore be made for possible errors in these matters. It is probable, however, that at a temperature of about 7,000°, the whole earth would be in a molten state. Now, as it continued cooling, a crust would be rapidly formed all round it, just as we see at the present time when molten lava pours out of a volcano it quickly hardens and cools, so that it may be walked upon, although a few inches down it may be glowing with heat. It is like a bad conducting "cosy" suddenly put over the whole globe, separating the intensely heated interior mass from the cold exterior regions of space. The regular cooling process would now be set up; heat slowly pouring, if the expression may be used, from the hot centre outwards through the crust, and thence radiated into space. In the lapse of time the whole globe would be in a condition similar to the iron ball we formerly referred to, extremely hot at the centre, and getting gradually cooler and cooler as we approach the surface. Now we have evidence that this is really the case, for we find the temperature of the earth gradually increases as we descend into its interior.† The question is, then, can we tell from these considerations, and from the rate of increase of the earth's underground temperature, how many years must have elapsed since the first hard crust of the earth was formed? To be able to do this we must know how much heat it would require to raise the whole earth to a temperature of 7,000°, or in other words, how much ice-cold water that amount of heat would raise 1°. It is very evident that we can at best only make an approximate guess at this, as we cannot get at the greater part of the material whose capacity for heat we are thus to measure. Further, we must know how much heat will pass through the earth's crust by conduction in a given time. This problem is more within our reach, as we can measure the conductivities of different rocks by methods analogous to those already described. There is also, however, an element of uncertainty here, as we cannot measure these conductivities under the same conditions as the temperature, pressure, &c., which obtain in the crust and deeper parts of the earth.

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* "Getting Warm:" "Science for All," Vol. III., p. 268.

† "Science for All," Vol. II., p. 111.

Notwithstanding these difficulties, however, Sir William Thomson, making every allowance for errors in his interesting speculations on this subject, concludes that the time that has elapsed since the main part of the earth's crust was first formed cannot exceed four hundred millions of years, and probably is as short as twenty millions.

Thus we see that, by the application of principles which are daily exhibited around us, we may arrive at results of the highest practical and scientific importance, and, although we may not at first have reached absolutely correct conclusions, still the way is pointed out by which interesting problems may be solved, and the range of science vastly enlarged.

A MUSSEL.

By Dr. Andrew Wilson, F.R.S.E.

THE mussel, like the oyster, is a "bivalve"—that is to say, its shell consists of two halves, each of which, in zoological language, is a "valve." This preliminary observation is not without its value as leading to an appreciation of some characters of the oyster and mussel class. A "bivalve" shell is well-nigh the exclusive possession of the mussel and its kin. There happens, however, to exist another group of shell-fish, known as *Brachiopoda,* and this class is found to possess a shell consisting of two "valves" or pieces likewise. Hence one of the first items in molluscan information is that which seeks to draw rational distinctions between the shells of mussels, oysters, and the like, and the Brachiopods. Nothing can well be easier than to draw such distinctions. A fair starting-point may be found in the mussel itself. Take a mussel—either the fresh-water or salt-water species will do—place it in its native element, and study first of all the ordinary features of uninterrupted and placid molluscan existence. The shell is seen, first of all, to consist of two valves, which are equal in size and similar in form. It is, therefore, perfectly justifiable to call the mussel's shell *equivalve.* The same remark applies to the shell of a cockle or of a clam.

The oyster's shell is certainly *inequivalve,* on the other hand, for we find one of its halves much better developed than the other. That, however, is an exceptional case, and arises from the oyster's habit of fixing itself in the mud of its native waters, to form, in company with thousands of its fellows, an oyster "bank." Fixation of the oyster's body leads thus to the over-growth of one valve of its shell as compared with the other. Each half, or valve, of our mussel's shell (Fig. 1) may be compared roughly to a cone. It is hollow within, and has, moreover, a narrow or pointed end and a broad extremity. The more pointed end is the hinder extremity of the shell, and the broad end is its front, or anterior border. We may note at present that in speaking of the ends of the mussel-shell as "front" and "hinder" extremities, we do so in relation to the living structures that shell contains. The mouth exists towards the broader part of the shell, hence, by right and courtesy that portion may be named the front of the structure.

When a living mussel is observed in its native *habitat* it may be seen to protrude from between the valves of its shell a soft fleshy organ we term the "foot." This "foot" (*f*, Figs. 1, 4) is shaped not unlike a ploughshare, and by its help the fresh-water mussels burrow in the mud of their rivers; whilst, as we shall hereafter see, the marine mussels spin, by its aid, a bunch of strong threads, serving to tie them to fixed objects. But our notice of a living mussel has taught us something more about the shell of the animal. We may now observe that the valves of the shell can be separated along one edge: that by which the foot protrudes. The opposite edge is that by which the valves are connected together. The former or lower edge we shall name the *ventral border* (*ve*) of the shell; whilst the latter, or upper border, we may term its *dorsal surface.* The "back" of the shell is therefore the part where the hinge is placed; and we can discover from an examination of the living animal that its heart being situated in this region, and the foot being developed below, the true upper surface of the shell is really its hinge-line. We have thus mapped out fairly enough the regions of the shell: that is the broad front where the mouth is found; the hinder border of the shell is its opposite extremity; its upper surface, or "back," is where the hinge is placed; and the lower or ventral edge is that by which the shell opens. The mussel has thus a right and a left side, and we speak of its valves as right and left "valves." Naturally, and having regard to the living animal's structure within, the shells lie right and left, and are *lateral* or "side" organs. It is easy enough in most shells of the mussel class to tell which is the right and which the left valve. Taking such a shell as a *Cytherea*, we look for the *umbo*, or "beak" (Fig. 2, *u*), the prominent projection on the back of the shell. Keeping the beak and hinge above, we turn the shell so that the beak points forwards. In this position that will be the right, and that the left valve which corresponds with our right hand and with our left hand respectively. The valve chosen for illustration (Fig. 2) is the right valve of the shell in question.

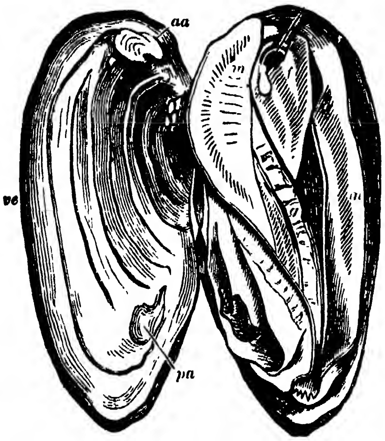

Fig. 1.—Anatomy of Mussel and Internal Markings of Shell

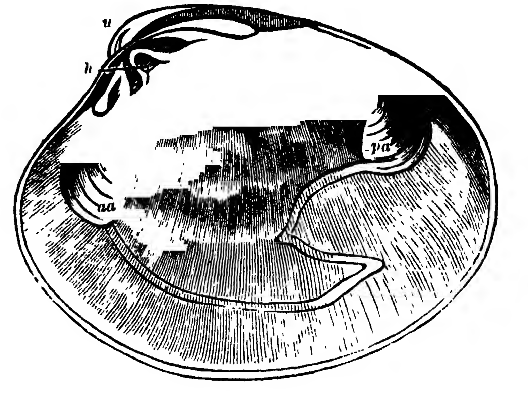

Fig. 2.—Shell of Cytherea (right valve) showing Internal Marks.

Such is the disposition of the mussel-shell in reference to the animal it contains. Let us next inquire into the mechanism by means of which the shell opens and shuts. The requirements of mussel life necessitate the opening and closure of the shell, because the animal demands, like every other member of its kingdom, food and oxygen. The normal condition of a mussel is to lie with the valves of its shell slightly apart. If we strew indigo or carmine in the water around, we shall find this material swept in at the front extremity and swept out at the hinder extremity of the shell. This action shows the presence of constant water-currents flowing in the direction just indicated. How these currents are produced and maintained we shall discover hereafter. The open condition of the shell, however, it may be remarked, favours thus the inhaling and exhaling of water, whereby the diving animal is supplied with food and with air. Now the shell of the mussel is opened and kept open by a different mechanism from that which shuts it. When we touch a mussel or oyster-shell, the valves close at once with a power that bespeaks very plainly muscular force of no mean order. The shell, then, is closed by muscles. There is no difference in respect of the action in question between the mechanism which moves my pen over the paper and that which closes the mussel's shell. In both cases a peculiar tissue, called *muscular tissue*, exists, and is disposed in bands or fibres. When stimulated, either through nerves, or it may be directly, these fibres contract, and in so doing bring together those parts between which they are attached—bones in the case of my fingers, valves in the case of the shell. An inspection of the mollusc's shell shows us the site of the muscles in question. At either end of the shell we see on each valve a shallow rounded impression. If we dissect a mussel we shall find a large mass of fibres stretching in these situations from one shell to the other. These are the *adductor muscles* of the animals, so named because they draw the valves together—that is, they close the shell. One we name the *anterior adductor* (Fig. 1, *aa*), because it lies close to the front edge of the shell; the other is named the *posterior adductor* (*pa*), for the opposite reason. Some shell-fish, and notably the oysters, have but a single muscle. The impression of the single muscle may be readily seen by looking at the interior of an oyster's shell. From what has just been said, it will be plain that it is the efforts of this great band of fibres to keep the shell closed against the impression of the oyster-knife, which causes all the trouble in opening an oyster. Once sever this adductor muscle, and the bivalve lies at our mercy for the performance of the other processes incidental to the toothsome repast. The art of opening the mollusc is really that of hitting the seat of the adductor muscle; and there is thus something to be gained by a knowledge of natural history even in the mundane sphere of the oyster-opener.

If the valves of the mussel's shell are kept approximated by the action of its adductors, how, it may be asked, is the shell opened? Let us bear in mind that the open condition of the shell is, for nutritive reasons, the natural state of the mollusc. Does Nature, then, give the animal the trouble of opening the shell by other muscular bands? If closing the shell is, as we have noted, an act of exertion, and, like all muscular acts, one involving considerable tissue-waste, is the mussel's life spent in one round of continuous exertion between the acts of shutting the shell when danger threatens and of opening it for the reception of food? The replies to these queries are readily found in an inspection of the shell itself. Outside the valves, at the hinge of the shell, we find a strong horny structure, called the *external ligament;* inside the shell, at the hinge likewise, we find another (or *internal*) ligament. The use of these bodies will be readily understood; for if we press together the still connected valves of a dried mussel-shell, and thus imitate the muscular movements of the animal, we shall find these ligaments, dried and horny as they are, to resist our pressure, and to force the valves open as by a spring when our pressure is released. Clearly, then, the action of these ligaments is simply a mechanical one. Like pieces of india-rubber which are compressed when the valves are closed, they open the valves when the pressure is removed by their elastic recoil. Thus, if the normal state of the mussel's shell is an open one, we see how that condition is maintained mechanically, and without any exertion on the part of the animal. As by a self-acting spring, the shell is kept open permanently, so to speak. It is only when the sharp and sudden closure of the shell is necessary, that muscular action, involving wear and tear, is permissible. Thus Nature husbands the powers of the animal, and exhibits a wise economy in the distribution and display of her forces.

The history of the mussel's shell includes a knowledge of its formation. When we open a mussel we observe a soft brown membrane lining the interior of each valve, but free and disconnected at the lower margin of the shell. This soft membrane is the *mantle* (Figs. 1, 4, *m*, *m*), or *pallium* of naturalists, and on this structure, wherever found, devolves the formation, growth, and repair of the shell. When the shell itself is examined, we can perceive that it exhibits a layered appearance. The successive ridges of the shell indicate the lines of its growth. It increases in breadth by new layers being added to the margin of each valve, and it likewise grows in thickness as well. That edge of the mantle which is attached round the lower or open edge of each valve, is found to possess glands which secrete lime and add this limy material to the shell. The thickness of the shell, on the other hand, depends on the general or outer surface of the mantle lining the inside of each valve. This surface forms the well-known *nacre*, or *mother-of-pearl* layer which we see in most shells, and which in the pearl oysters and pearl mussels forms "pearls" when the nacre coats some foreign body, such as a particle of sand. The structure of the "mother-of-pearl" layer shows it to consist of layers which refract the light, and give to this substance the iridescent play of hues and colours it is seen to possess. The outside of the fresh-water mussel's shell is covered by a horny layer, called the *periostracum.* This layer protects fresh-water shells especially against the dissolving action of the carbonic acid gas existing in the water, and which otherwise would attack the lime. Thus we discover that the mussel, like a large number of other animals, builds up a limy skeleton—the shell—outside its body. In respect of its manufacture of lime, the mussel is, however, by no means singular. Some of the lowest animalcules (*Foraminifera*) inhabiting the sea-depths make shells of carbonate of lime, others using flinty material. Corals illustrate lime secretion on a large scale; sea-urchins utilise this material in the formation of their shells; and the back-boned animals, from fishes to man, similarly elaborate lime to form the bony framework we name the "skeleton."

The remaining details concerning the "shell" of the mussel may be summed up by saying that whilst it is "equivalve," as we have seen, it is also "inequilateral." It is not equal-sided, as a glance at the shell will show. Now, the shell-fish already mentioned under the name of *Brachiopoda* possess shells which are "equilateral" but "inequivalve;" so that these brachiopod shells are opposed in these respects to the mussels and their allies. Further, brachiopods open and close their shells by means of muscles, and the spring ligaments of the oysters and cockles, &c., are wanting in these forms. In a word, the only likeness between the one group of shell-fish and the other consists in the possession of a “bivalve” shell. When it is added, further, that brachiopods are not at all plentiful shell-fish, but are a race slowly dying out of existence and represented chiefly in warm seas, it can be understood that any “bivalve shell” picked up on our coasts must belong to the oyster and mussel class. That class, we may profitably remember, receives the name of *Lamellibranchiata*, or “plate-gilled” molluscs—a name applied to them from the structure of their gills.

The internal economy of the mussel is in itself an interesting study. We may discover that in the way of nerves, digestive apparatus, heart, and breathing organs it is well supplied. Beginning with the digestive system, as a convenient portion of mussel anatomy, we discover the mouth (Fig. 1, *mo*) at the front border of the shell. The mussel has no head. In this respect it is a decidedly lower animal than the whelk (Fig. 3) or snail—its near neighbours of the class *Gasteropoda*. The possession of a head, let us note in passing, is invariably the sign of a high organisation; for head development means and implies the possession of special sense-organs, eyes, &c., and of a nervous system modified and developed over that of the headless organism. A snail or whelk is unquestionably a livelier animal than a mussel or oyster. It moves about within its world with tolerable, if with slow and stately activity; and it has eyes, tentacles or feelers (*tt*), and other possessions belonging to the senses adapted to bring it in more or less intelligent contact with the outer world. But the mussel and its relatives are, as a rule, vegetative in their life and character. They do not possess even the humble appreciations of snail existence, and their sense-organs are neither so conspicuous nor so well-developed as are those of the Gasteropod race. The idea has been ventilated by some authorities that the mussels and their kin are examples of “degeneration” in animals: that is, they have gone back in the world, whilst the snails have progressed and advanced. This view is supported by the fact that the two groups develop at first much in the same way; retrogression and backsliding being regarded as the lot of the mussel tribe, and advance as that of the higher Gasteropods.

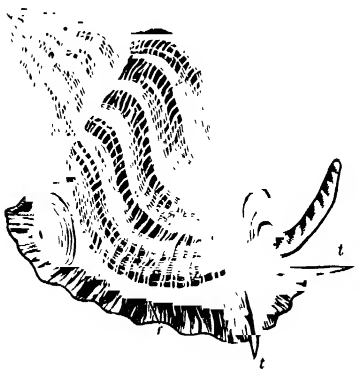

Fig. 3.—Whelk.

This digression, interesting as it is, has led us away from the digestive system of the mussel. The mouth—returning to our original topic—is bounded by four feelers, or tentacles, which probably serve to guide the food-particles into the mouth-opening, and may likewise subserve the sense of taste. No hard parts of the nature of “teeth” or “jaws” exist in the mussel or its kind; and in this respect these molluscs exhibit a difference from the snails and whelks, which have a curious tongue, and a rasping apparatus as well. To the mussel's mouth succeed throat, stomach, and intestine respectively. The digestive system, as in every other animal above the rank of the sea-anemone, is thus a tube shut off from the body cavity; but, as in higher animals, the mussel possesses, as addenda of its digestive system, certain “glands,” of which the liver is the chief. The glands secrete or manufacture, from the blood, matters of use in the digestion of the food. Thus a very large liver in the mussel secretes *bile*, as does man's liver, and contributes a fluid of great importance in the universal digestion of nutriment. The mussel has no *salivary glands*, such as many other molluscs possess; nor does it number a *sweetbread* or *pancreas* amongst its digestive belongings. But close by the stomach a curious rod-like body, the *crystalline style*, is found, lying in a little pouch-like fold. The use of this body is quite unknown (Fig. 4).

The animal commissariat, represented by the digestive system, is devoted to the production of a fluid, namely, *blood*, which, in its turn, nourishes the body—that is, affords material for growth, and supplies the needful matter for the repair of the body's wear and tear. The mussel's blood is colourless, but when placed under the microscope it is seen to contain small masses of protoplasm, or *corpuscles*, which exhibit these curious movements (seen in the white corpuscles of our own blood), and named *amœboid movements*. The due circulation of the blood through the body is as much a necessity for the nourishment of an animal's frame as the circulation of money is a vital condition of commercial activity.

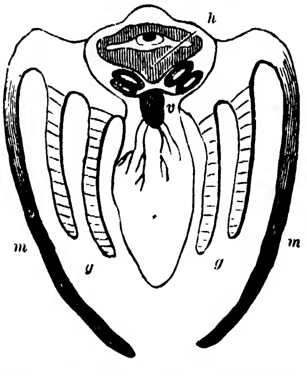

Fig. 4.—Diagrammatic Transverse Section of Mussel.

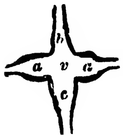

Fig. 5.—Diagram of the Mussel's Heart.

a, *a*, Auricles opening into Ventricle, *v*; *b*, Anterior, *c*, Posterior, Aorta.

Nature therefore provides the means for circulation in the form of a pumping-engine, called the *heart*, and of a set of tubes named *blood-vessels*. The mussel's heart lies in its back, just beneath the line corresponding to the hinge-line of the shell, and along which the mantle-lobes are united. Enclosed, like our own heart, in a sac, or bag, called the *pericardium*, the mussel's heart may be said to perform half the duty and function of the heart of man. The latter organ sends impure blood to the lungs to be purified, and it also propels pure blood throughout the system; but the mussel's heart is adapted only to send pure blood through the body. It corresponds in function, therefore, with that side of man's heart we name the *left side*, and is hence named a *systemic* heart. Any heart is simply a hollow muscle. It is hollow to allow blood to pass through it, and it is muscular that it may contract to propel the blood through the vessels. The mussel's heart is three-chambered (Fig. 5); it consists of a larger chamber—the *ventricle* (*v*)—and two smaller chambers—the *right* and *left auricles* (*aa*). The auricles receive the purified blood from the *gills* (Fig. 4, *g*, *g*) and propel this blood into the ventricle. When the latter chamber contracts, the blood is forced out into the vessels. These latter consist of main tubes or pipes leaving the ventricle, and which, growing smaller and smaller as they branch out into the body, ultimately appear to lose themselves in the ill-defined spaces existing between the various organs of the body.

Thus all the organs and tissues receive their supply of blood nourishment. But this is not the whole work of the blood-circulation, either in the mussel or in any other animal. When the blood has performed its nourishing duties the aspect of its stream alters. It no longer is to be regarded as a pure nutrient current; on the contrary, in the course of its travels it has absorbed from the tissues it nourished waste materials. These it carries with it on its return journey, to convey them to certain organs, named *organs of excretion*, and of which the *skin*, *lungs*, and *kidneys* of higher animals are the best examples. Thus the work of these three organs is, in reality, that of getting rid of waste matters. In the mussel there is waste and repair, as in ourselves; and the waste products of the mollusc are practically identical in kind with the effete matters of the human frame. Thus the mussel will excrete *carbonic acid gas*, *organic matters*, and *nitrogenous waste matters*, such as the kidneys of higher forms separate from the blood. For this reason, then,—that waste matters may be excreted and given forth to the outer world—the blood of the mussel makes a return journey to the *gills*, and to a certain body which receives the name of the *organ of Bojanus*.

The mussel's gills, as we have already noted, are highly characteristic organs of the animal's body. The *gills*, or *branchiæ*, number four. They are situated two on each side of the mussel's body, and as they present the appearance and structure of thin plates in all the mussel class, we find that group to receive the name of *Lamellibranchiata*, or "plate-gilled" Mollusca. When we open the mussel or oyster we can detect the gills as two delicate layers (Fig. 4, *g*, *g*) on each side of the body, lying just within the mantle, and looking like fringes of the latter structure. Each gill consists of two delicate *lamellæ*, or plates, which, when magnified, exhibit a barred arrangement bearing a dense network of blood-vessels. A fragment of living gill placed under the microscope shows a surface richly covered with the minute vibratile hairs called *cilia*. These, by their constant motion, create currents in the water admitted to the body-cavity, and thus provide for the constant renewal of the medium which contains the desired oxygen for the work of blood-purification. Thus we can perfectly understand why in a living mussel incessant water-currents enter and leave the shell by its front and posterior extremity respectively. These currents are excited by the cilia of the gills, which thus functionally represent the breathing movements of higher animals, whereby the air is renewed continually within the lungs. Thus, as impure blood flows from the body into the gills it gives off its waste matters to the inhaled water, and it absorbs the oxygen which that water bears. The effete water is wafted out of the mussel's shell by ciliary action, and the pure blood streams from the gills into the heart's auricles. Thence it is sent to the ventricle, and last of all passes to the body, where it will again perform the same round of duties, and be now and then recruited by fresh supplies of matter derived from the food.

The *organ of Bojanus* (Fig. 6) has been mentioned as a structure which, like the gills of the mussel, assists in getting rid of the waste matters of the mollusc's frame. This body is a kind of sac, lying under the pericardium, or heart-covering, and opening into the latter cavity. One part of this organ exhibits what is termed a *glandular* structure, that is, it is adapted to separate from the blood matters of waste nature. It is believed that the organ of Bojanus corresponds in function to the kidneys of higher forms. Concretions of *uric acid*, a substance associated with the kidneys in higher life, are found within the organ of Bojanus, which thus is adapted to remove from the mussel's circulation the special waste products which arise from the decomposition of nitrogenous matter.

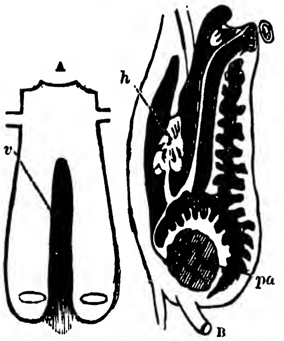

Fig. 6.—Organ of Bojanus: A, Diagrammatic Plan; B, same in Diagrammatic Section.
h, Heart, with which the organ of Bojanus lies in close relationship; *v*, great vein; *pa*, posterior adductor muscle.

The "foot" of the mussel, already alluded to, demands a brief notice as an organ of great importance in the bivalve class. The snail and whelk are seen to crawl upon a broad foot surface, representing the high development of the lower integument of the body (Fig. 3, *f*). So, also, in the mussel and its kin, the "foot" is a development of the lower surface of the body in the middle line. As the "gills" are really processes of the mantle in their nature, so the foot itself may be viewed as a special development of the latter membrane likewise. In the oyster, the foot is but sparingly developed; in the fresh-water mussel it is an organ of motion; in the marine mussels it secretes the *byssus*, or beard; in the cockle it is used like a gymnastic pole for leaping; and in the razor-shells (*Solen*), it forms a most efficient burrowing tool. In the fresh-water mussel the foot (Fig. 1, *f*,) appears before us as a highly muscular organ, the arrangement of whose fibres reminds one of the similar structure seen in the human tongue. In the salt-water mussels a deep groove exists in the foot, and into this groove a fluid matter, secreted by special glands, is poured. This matter sets firmly in the groove, as molten wax sets in a mould, and when the foot is retracted, a thread formed of the now solid matter can be drawn out, and added to the bundle of threads already formed. By means of these threads the mussels attach themselves firmly to fixed objects. Any one who has picked up a mussel on the sea-beach, fastened to objects often exceeding itself many times in weight, will have been enabled to form some idea of the stoutness of the mussel's "beard."

The current of mussel-life may in all respects be said to flow uneventfully and placidly along. Few elements enter into that existence to disturb its patent harmony, and the need for nerves and sensory belongings might be regarded as being well-nigh extinguished. Still, no living being exists without, in one fashion or another, influencing the universe in which it lives, or without, in turn, being acted upon by the external world. Even mussel-life has its relations to the outer universe in the shape of a constant inflow of water and food particles; and it likewise possesses its more evident acts of "sense" in the sharp closure of the shell already noted. The symptoms of mussel-existence would, therefore, of themselves make certain the truth of the inference that the animal possesses a *nervous system*, forming a link between the animal itself and the world in which it lives. Careful dissection shows that, like every other nervous system of any importance, that of the mussel consists of certain ruling and controlling parts, called *nerve-centres*, or *ganglia* (Fig. 7, A, *c*, *p*, *b*), and of conducting and transmitting parts, called *nerves*, or *nerve fibres* (Fig. 7, B). Of the former, the mussel possesses three. There is one ganglion, or nerve-mass—really consisting, like the others, of a concentrated pair—situated close by the mouth. This we name the *cerebral*, or *cephalic ganglion* (*c*), from its analogies with brain in ourselves. Another nerve-mass exists in the foot, and is named the *pedal ganglion* (*p*); whilst a third (*b*, the branchial ganglion) is placed close by the posterior adductor muscle, and not far from the heart. These three nerve-masses are connected by nerves, which, like telegraph-wires, serve to convey from centre to centre the impulses and impressions that make up the sum total of mussel-life. The action of nerves in the mollusc is like that of the nerves in higher existence. Impressions received by the nerves are transmitted to some nerve-centre, and are thence "reflected" to some other part of the body, producing movement, or otherwise affecting the life of the organism. This theory of nervous function we name "reflex action," a topic which has been already discussed and ventilated in these pages.

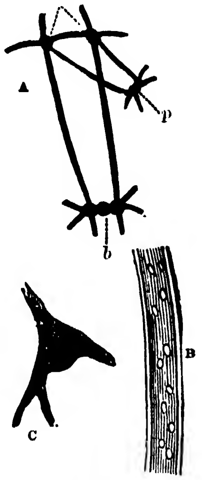

Fig. 7.—Nervous System of Mussel: A, Distribution of Nerves; B, Nerve Fibre, showing contained Granules; C, Ganglionic or Nerve Corpuscle with Nucleus, and giving off branches.

Sense-organs, forming the "gateways" of the nervous system, are represented in our mussel chiefly by rudimentary "ears." Close by the nerve-mass of the "foot" are two small "sacs," each containing a living particle, called an *otolith*, suspended in a clear fluid. This particle exists in a state of constant vibration; and there can be little doubt that its function is that of intensifying the vibrations of sound-waves, and of transmitting these to the neighbouring nerve-mass. There, we may believe, they become converted into a "sensation" of sound, upon which, if necessary, as upon "information received," the mussel may in due course, act. The sense of touch is probably represented by the tentacles placed around the mouth, and, perchance, taste may be subserved by these organs as well, seeing that taste and touch in higher animals are nearly allied senses. Eyes do not exist in the mussel, but they are not always wanting in the mussel's relations. If a scallop-shell (*Pecten*) be dredged from its native waters, and be closely watched, a row of sparkling, bead-like structures will be seen to fringe the edge of the mantle every time the mollusc opens its shell. These animal gems are the scallop's "eyes," whereby light-rays are appreciated and acted upon, not, certainly, with the range of higher vision, but still conformably to the wants and requirements of lower existence.

Mussel-life begins, as all other animal existences practically commence, in an egg. Immense numbers of eggs—as many as 3,000,000, or even more—may be produced by a single mussel, and the eggs are retained within the gill-chamber of the female mussels until the earlier stages of development have been exhibited. As it escapes from the egg, the young mussel is so unlike its parent that it was first named *Glochidium* (Fig. 8, A), and was esteemed a parasite, because it is frequently found attached to the tails of fishes. This larva possesses a bivalve shell (B, C), and an adductor muscle for the shell's closure. The lower edges of the valves are provided with hooks for attachment, and the mantle can also be discerned. When the larvæ are swept outwards from the body of the parent, and attach themselves to fishes (D), they grow rapidly; the shell assumes the likeness of that of the adult; the foot increases in size, and the gills undergo fuller development. At last the "Glochidium" drops from its hold, and appears in all respects, save in size, the perfect representative of the adult mussel (Fig. 8).

An examination of this very familiar mollusc may teach us certain facts relating to natural history study at large. We learn from this brief recital of its history that the mussel is a Mollusc, in virtue of its possessing a true "shell," and also in that it exhibits the characteristic features of molluscan structure in the shape of its mantle, gills, foot, digestive system, and other points. And we also discover its relations to the whelks and their allies in those modifications of its organs which have led us to designate the mussel tribe as of lower rank than the whelk, periwinkle, and snail order. Thus, not merely a generalised view of a great sub-kingdom of animals, but a more special knowledge of the varied types that sub-kingdom includes within its limits, may be gained by a study of the mussels, than which no more familiar denizens of our sea shores, ponds, and rivers can be said to exist.

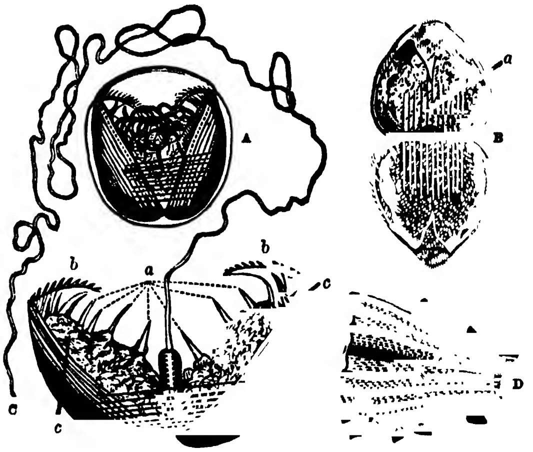

Fig. 8.—Development of Mussel.

A, Glochidium Larva still within the Egg: *a*, Byssus; B, Shell of Glochidium widely opened, showing Adductor Muscle, *a*; C, Glochidium viewed from the side, showing Hooks of Valves, *b b*; Muscular Folds, *c c*, and the three pairs of Filamentous Organs, *a*, springing from the Mantle-lobes along the Extended Byssus; D (*After Carpenter*), Young Mussels on Tail of Fish.

THE WONDERS OF ELECTRICAL INDUCTION.

T is perhaps no single phenomenon in nature which has puzzled the human race more, from the very earliest ages up to the present day, than the strange power which a magnet possesses of attracting to itself bodies of iron or steel. It is, of course, very easy to understand how one object can move another if there is any tangible mechanical connection between them; and we can even go so far as to believe that a vast body like the sun may attract the earth and hold it in a certain orbit; or the earth, the moon. But when it comes to a simple bit of metal pulling to itself another bit of metal, and to seeing a simple bit of iron (to our senses no way different from any other piece of iron) seemingly call to itself a second piece, actually making the latter move over a considerable distance to come to it, or, more strange still, compelling a quantity of iron filings not only to move, but to arrange themselves in regular curves about its ends, there is something which amounts to mystery; which was, indeed, a mystery for centuries and centuries, and which is a mystery still.

Every piece of iron has not this curious property; that we can easily prove. But there is evidently something contagious about magnetism, for we have only to rub a non-magnetic piece of iron in a certain way with a piece that is magnetic, and, behold! both are magnets. And that is even more curious yet; in fact, it is not very many hundred years ago that we might have been burned as sorcerers or witches for daring to discover any such extraordinary state of affairs. But among the wise people who dwelt on this earth ages ago, were some whose wisdom took a more practical turn. They found out that if a magnet was made in the form of a needle and placed on a pivot, it would always point north and south; and so they navigated their junks safely about the Yellow Sea by its aid for centuries, while the sailors of the other hemisphere were hugging the shores of Europe, or steering by the North Star when the clouds and the fogs would let them. Now compass needles had to be made, forged out of the iron. Natural magnetic iron does not lend itself at all well to the manipulation, and besides, when heated highly, is apt to lose its magnetic property. And so it is exceedingly likely that the Chinese first made their needles from ordinary iron, and then magnetised them from the loadstone. And that was, perhaps, the beginning of the leading in of magnetism from one body to another; or, in other words, the magnetising of the compass needle was in all probability the first wonder of induction turned to useful account by man.

Whether before this discovery by the Chinese or afterward nobody knows, it was found out that amber, if rubbed, would act very much like a magnet, only instead of attracting nothing but iron, it would not attract iron at all, but light substances such as feathers or particles of dust. About two thousand years after that was found out, Queen Elizabeth's physician, Dr. William Gilbert, in the beginning of the seventeenth century, announced that there were other things which, when rubbed, would act just like amber; and so really began the grand science of electricity with a phenomenon of electrical induction; for it is by the *induction* of properties like to those given them by rubbing, that the amber, and jet, and glass, and other substances are enabled to exercise their attractive powers.

Two centuries rolled by. Men learned more and more of the most wonderful of all forms of universal energy, until they mastered the lightning, and set it flowing peacefully and silently through slender wires. And then one day—by mere chance, it is said—a Danish professor, Hans Oersted, noticed that if a magnet needle freely suspended were brought near to a wire through which a current was passing, the needle would be influenced to set itself across the wire. A few months afterwards Arago found that a wire under like conditions would draw to itself iron filings, as if it were a magnet. And thus came to light the knowledge of another form of electrical induction, which is the most important of all, since it led directly to the great achievements which have brought electricity into the every-day service of man.

There are consequently three forms of the phenomenon known as induction: magnetic induction; the induction of the static or quiescent electric charge; and the induction of the electric current moving (apparently) along a conductor. In the first case magnetism, in the others electricity, is induced from a body in which one or the other condition or form of energy is present, in another body in which it is originally not present. In all three cases this strange power is, or may be, exerted over an interval existing between the bodies, so that we might almost imagine, as old Robert Boyle expressed it two hundred years ago, that "glutinous steames" emanate from the inducing body and seize upon the induced body and so move it. Pretty much everything about electricity partakes of the marvellous, but this idea of induction is bewildering when we try to reconcile it with our notions of time. A magnet, so far as we can perceive, attracts a body of iron instantly; so does a wire carrying a current the filings placed near it, or a piece of rubbed sealing-wax a scrap of paper. In every case it is certain that magnetism or electricity is "induced" in the attracted object, before it can be moved. But when? in what period of time? We cannot even imagine. This is the very dividing line between physics and metaphysics, whereat we are landed by more than one electrical phenomenon.

Between the phenomena of the three forms of induction above referred to, there is much

A

similarity in essence, though the details are somewhat different.

To illustrate the effect of static induction, suppose we have a body, A (Fig. 1), which is electrified by rubbing or by communication with an electrical machine. If we bring near to this body a pith ball, B, suspended by a silk thread from a glass rod, we shall see the ball drawn toward the body A. The nearer we allow the ball to come to the electrified substance, the more strongly will it be attracted, so that it seems as if there were a sort of atmosphere, or field of force, surrounding the end of the body A, which is denser or more powerful in its coercive effect near to the body.

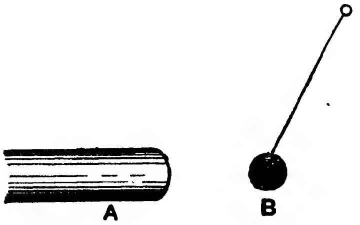

Fig. 1. Induced Electricity.

Around the poles of a permanent magnet there is evidently also a field of force. If we bring a piece of iron into this field, it becomes magnetic; so that if in Fig. 2 N is the north pole of the magnet, we shall find that not only will magnetism be induced in the iron, but the end of the iron brought near to the north end of the magnet will show magnetism of opposite name, while at the farther end will appear magnetism of the same name.

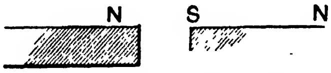

Fig. 2.—Induced Magnetism.

Lastly, let us assume a wire, A, connected in circuit with a battery, and so arranged that we can establish or break the circuit at will. Suppose the circuit in this wire moves in the direction of the arrow, 1. Suppose, further, that we have a wire, B, connected at both ends with a galvanometer which will indicate the presence of a current. If we start the current in wire A, we shall find a momentary current moving in the opposite direction in wire B; if we strengthen the current in wire A, again, a momentary current in the opposite direction will appear in wire B; finally, if we move wire B nearer to wire A, once more the electric throb, still moving in the opposite direction, will traverse wire B. On the other hand, if we stop the current in A, or diminish its strength, or move A away from B, then a current in B will be set up in the same direction as that originally existing in wire A.

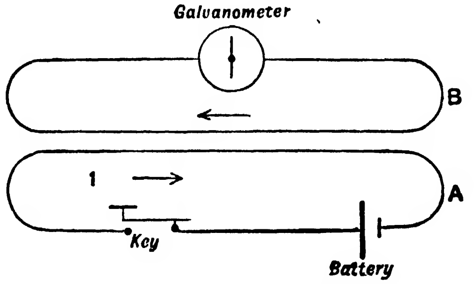

Fig. 3.—Induced Current.

Not only will electric currents induce other electric currents, but magnets can be made to induce currents; and, conversely, currents will induce magnetism. If into a coil of insulated wire we introduce a magnet, as in Fig. 4, we shall find that whenever the magnet enters the coils, a current in one direction will occur in the wire *ff'*; and when it recedes from the coil, a current in the opposite direction will appear. A curious application of this principle is the utilisation of the earth itself, as a huge magnet, to produce currents in coils of wire rotated in a plane at right angles to the dip or inclination needle. If we cover some wire with insulating material, and wind it around a piece of iron, as in Fig. 5, that iron will become a magnet by induction as long as a current continues through the wire, and cease to be a magnet when the current stops, and in this way is made the electro-magnet.

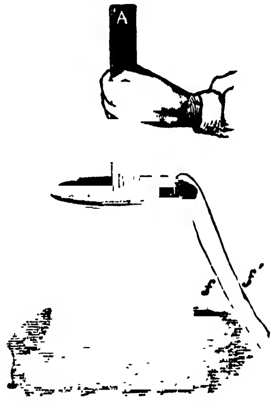

Fig. 4.—Magneto-electric Current.

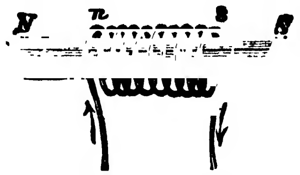

Fig. 5.—Electro-Magnet.

All these phenomena, thus in the briefest way outlined, have been carefully investigated, and their laws determined, and upon them rest nearly all the great electrical achievements of modern times; but as these are described in special articles, the details need not be given here. In telegraphy, the current established by the pressure of a key by the operator at one end of a line, passes around the coil of an electro-magnet at the other end, and the soft iron core in that coil becomes a magnet by induction. This magnet then operates the receiving apparatus; meanwhile, as the current is travelling over the wire, it may induce other currents in wires near by, so much so as to interfere with the working currents on these conductors. Very often telephonic communication is impaired in this way. In the telephone, as will appear in a future article, almost every step in the process depends upon induction. In electric lighting, immensely powerful currents are induced in the coils of wire which form the armatures of the dynamos, and these currents cause the incandescence of the glow lamps or the dazzling arcs which illuminate our streets.

Currents of electricity of immensely high pressure are obtained from an apparatus known as the Induction Coil, a simple form of which is represented in Fig. 6. This consists of a coil, A, of very fine insulated copper-wire, the ends of which are connected to the screws K, K. This is the secondary coil in which the induced currents are generated: it is fastened upon the movable frame S, which slides horizontally. The primary or inducing coil, B, consists also of many turns of coarser copper wire, and has, as a rule, a bundle of iron wires for a core. Whenever a current is made or broken in B, an induced current is generated in A; but, owing to the much greater length and high resistance of the wire in A, this current is much less in quantity but of enormously higher potential or pressure than the primary current in B. The induction coil, therefore, is a convenient means of converting a current of large quantity but low potential, such as that from a few Voltaic cells, into an induced current of small quantity but very high potential, such as that from an ordinary electrical machine. In order to effect the rapid making and breaking of the circuit, a contact-breaker is provided, which consists of an electro-magnet, E, which alternately attracts and releases an armature *a*, and this armature, being set in vibration, connects or interrupts the current with the screw *s*.

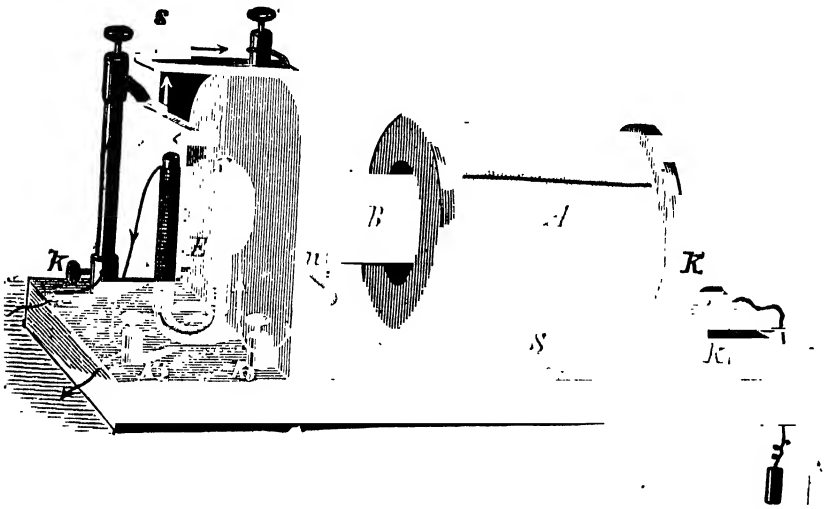

Fig. 6.—Induction Coil.

The most powerful induction coil in existence is that designed by the late Mr. Spottiswoode. The secondary wire is 280 miles in length, and contains 341,850 turns. With thirty Grove cells this apparatus produces a spark between its terminals forty-two inches in length, capable of penetrating a glass block six inches thick. The spark appears as a zigzag line of bluish-white light, accompanied by a crackling and hissing sound. A very elaborate series of investigations was made by Mr. Spottiswoode, by the aid of this coil, into the nature of the peculiar striæ or stratifications into which the electric discharge separates when passed through vacuum tubes. When the exhaustion of a so-called vacuum tube is carried considerably beyond the point which gives the best striæ and luminous effects, a new set of phenomena is produced, the residual gas in the tube developing so many new and curious properties that Mr. William Crookes, F.R.S., has asserted that the gas may, in fact, be regarded as matter in a fourth or ultra-gaseous state.

Induced secondary currents of electricity are much used in medicine, the human nervous system being very sensitive to abrupt electrical changes. The induction current produces powerful shocks, while the constant current from a battery is not noticeable unless many cells are used.

Two very sensitive measuring instruments invented by Professor Hughes depend for their operation upon electrical induction. The audiometer (Fig. 7) has two coils of wire (*a*, *c*) respectively at the ends of a scale rod, on which rod slides the coil *b*, which is connected in circuit with a telephone. The coils *a* and *c* are connected with a battery and a microphone, and near the latter a clock is arranged. The currents produced in coils *a* and *c* circulate in opposite directions, and it follows that at a certain point on the rod their influence upon the coil *b* becomes neutral, and the ticking of the clock can no longer be heard in the telephone. This position is indicated by zero upon the scale. The object of the apparatus is to test the powers of hearing. The telephone being placed to the ear, the nearer that the coil *b* can be moved to the zero point without the listener ceasing to hear the clock, the better is the listener's hearing.

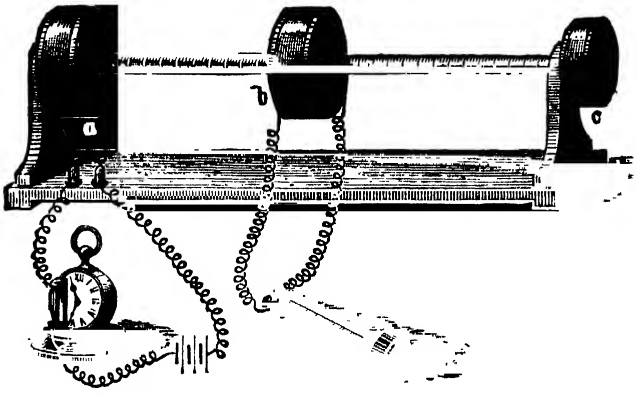

Fig. 7.—The Audiometer.

The induction balance (Fig. 8) is precisely similar in principle, but differently arranged, and consists of two cylinders of ebonite, upon each of which are two coils of insulated wire. The two upper coils are connected with a battery, a microphone, and a galvanometer, to form one circuit as shown, and the two lower coils are connected with a telephone to form a second circuit. The two lower coils are so arranged that the induced currents generated in them oppose each other, so that if the currents are equal no sound will be heard in the telephone. If, however, a piece of metal be introduced into one of the cylinders between its two coils, equilibrium is immediately destroyed, and the telephone begins to sound. It can be made mute again by adjusting the movable coil on the second cylinder, or by compensating for the disturbance in another manner. If a second coin be introduced in the place of the first, equilibrium will be maintained only when the second coin has the same form, weight, and composition as the first. This balance is so sensitive, that different results are obtained even when the physical condition of the coin only is altered, as, for instance, by hammering, casting, &c. The instrument has been adapted to the discovery of ores, detection of submarine mines, or torpedoes; and attempts have been made to locate by its aid the position of bullets in the human body. The apparatus was thus used for the first time upon the late President Garfield, but in that case unsuccessfully, as it was misled by metal springs in the bed, and gave indications as to the position of the assassin's bullet which afterwards were found to be erroneous.

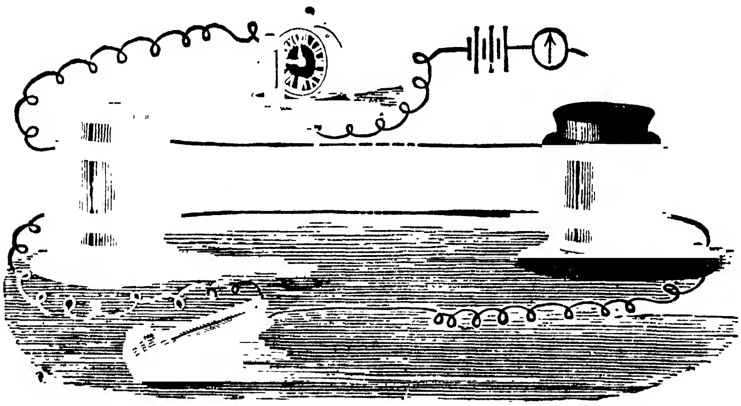

Fig. 8.—Hughes' Induction Balance.

The reader will have perceived ere this, that the ordinary commercial purposes of an electric current may be effected in two ways: we may use the current itself direct, or we may use the current which it "induces" in a neighbouring wire arranged parallel to the primary current. Here the water analogy is not so plain; because, of course, a running stream, no matter how swift and powerful the torrent, will not influence an object outside of it. We use the energy of the electric current, however, as much through induction as if we used the current directly. We cannot use the energy of moving water without mechanically dealing with the water itself; we can use the energy of an electric current, through the field of force which is created around it, without directly conducting the current out of its circuit. One of the newest schemes practically introduced for employing electricity on a large scale is that known as the induction system, sometimes called the Gaulard and Gibbs system, from its principal promoters. Messrs. Gaulard and Gibbs send an alternating current along the wire represented by the heavy line in Fig. 9, and every time the current in this wire changes direction—which it does, say, twenty times per second—a current is "induced" in a neighbouring wire, wrapped close to the heavy wire around a soft iron core. These "induced" currents are made to pass through lights, or motors, or other apparatus, and they can be used exactly like currents produced directly by machines; but the advantage of the system is, that since the main wire need not enter a house, or at least need not come near where people will be likely to come into contact with it, an enormous current can safely be sent along it, which might be dangerous to life if sent direct through the electric lamps in houses. The currents induced may be made as weak as desired; just strong enough, in fact, to work the number of lights required for one house; so that a very great number of lights may be controlled by one wire with perfect safety.

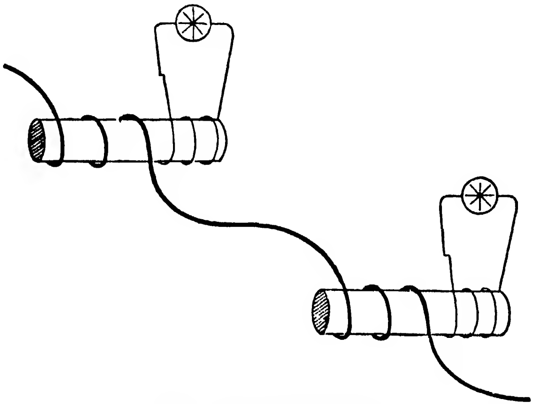

Fig. 9.—Induction System.

Since the first edition of this work was issued, induction currents have found a most important application in effecting communication with trains actually travelling on a railway. Phelps' arrangement depends upon the elementary phenomena described in connection with Fig. 3. A telegraph-wire is stretched all along the centre of the railway-track, through which any required message is sent. Another wire is fixed under the bottom of the train or guard's carriage, with which is connected some sensitive telegraphic receiving instrument inside the carriage. However fast the train is moving, if the two wires are not too far apart, a signal passing through the line-wire produces an induced current in the carriage-wire, which transmits the signals; or conversely, a signal sent through the carriage-wire can produce an induced current in the line-wire, and transmit the signal to the station. Communication has been effected in this way with a train running forty miles per hour. In another system, devised by Edison and Gilliland, induction is effected between the wires hung on telegraph-poles in the usual way, but brought nearer, and the metal roofs of the carriages, which are insulated and connected together end to end; or when this is impracticable, a wire is arranged along the roof. The receiver may be an ordinary telephone, with a sounder and switch to complete the circuit; or a pair of telephones may be worn permanently at the ears by a head-band. In Edison's system the receiver is connected with an induction-coil in such a way that the surface of the metal roofs acts as a condenser* to the coil, and increases the effect of the current in producing the clicks or signals of the Morse code. In 1887 a message was sent by this system from a train fitted by the American Consolidated Railway Telegraph Company, and running at sixty miles an hour, through the Atlantic cable to London in England; the same message being communicated to all the other trains running on the line. The cost of fitting this apparatus was stated to be about fifty dollars per mile for the telegraph line, and about fifteen dollars for fitting the car.

Such are some of the wonders of electrical induction unfolded by modern research. But by far the greatest wonder of all, if we could know it, would probably be the manner in which this induction is brought about; *how* an electric current flowing in one wire can beget a secondary current flowing in a wire at a distance. Our inability to understand this, or even what electricity itself is, has already been pointed out. The more we study the subject, the more mysterious it becomes; and we are finally compelled to acknowledge that a profound secret underlies all our facts, which we may, perhaps, never be able to wring from Nature.

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* For description of a condenser, see Vol. V., pp. 151, 152.

A SUPPOSED NEW PLANET.

By W. F. Denning, F.R.A.S.

THE late eminent French mathematician, Le Verrier, while conducting an investigation into the orbit of Mercury, became convinced that in order to explain trivial discrepancies which his calculations revealed, it was either necessary to assume the existence of an undiscovered planet revolving between Mercury and the sun, or that the computed mass of Venus as generally adopted was considerably less than the actual value. He was inevitably drawn to this opinion by the fact of certain perturbations becoming apparent in the movements of Mercury which could not be otherwise explained. Though he had allowed for such disturbing agencies as were known to have an influence upon the orbital motions of the planet, there yet remained a certain residue which could only be attributed to other forces. There must be a disturbing body somewhere, for the influencing action of Venus could not be greatly underrated, and analogy suggested that this body was situated close to the sun. That it had never been seen could not be held as strong negative evidence, because it must invariably be hovering close to the sun and overpowered in his intense brilliancy. Mercury himself is only to be perceived on rare occasions, and it is obvious that a planet even nearer to the sun than he is, could not, under ordinary conditions, ever be visible to the human eye. Such a planet would never depart many degrees from the sun, and would not be sufficiently distant, even at the time of his greatest elongations, to allow his detection possible at sunrise or sunset, when he would be above the horizon for a very brief space in the absence of the sun.

The publication of Le Verrier's conclusions drew attention to the subject, and set men thinking as to how such a body could be discovered. It could evidently be seen while traversing that part of its orbit situated exactly between the earth and sun, for on such an occasion it would present the appearance of a black circular spot crossing the solar disc rapidly from his east to his west side, and observers of the sun would be certain to distinguish it from the ordinary sun-spots by its special peculiarities of motion and appearance, which must immediately prove its planetary nature. It might also be detected during a total solar eclipse if the region around the sun were carefully scrutinised for such a body, but the great rarity of the phenomenon, and the fact that on such an occasion observers are already fully occupied with the wonderful spectacle of the eclipse, render the prospect of a discovery of this nature almost entirely out of the question. The probabilities inclined strongly in favour of the idea that it would be discovered, if at all, while in transit over the sun, for such transits would not be of unfrequent occurrence.

A country doctor named Lescarbault, residing at Orgères, in France, heard of Le Verrier's deductions,* and it recurred to him at once that he had, while observing the sun on March 26th of that same year, witnessed the passage of an opaque planetary object over it, but had delayed the publication of his notes, hoping to re-observe the mysterious body, and to complete certain rough calculations which he had been making to determine the elements of its orbit. Diffident as to his powers, he had hitherto feared to lay his approximate data before the scientific world, but now that its possible value became impressed upon him, he made it known. The supposed observation was not long in coming to the ears of Le Verrier, who, however, treated the tale of the obscure amateur astronomer with ridicule, until, on making further inquiries, he found there might be some truth in the rumour. He therefore determined upon personally interrogating the alleged discoverer, and thoroughly sifting the matter. This was done. Lescarbault was subjected to a rigorous cross-questioning, his instruments were examined, his methods investigated, and, without citing the details, it will suffice to say that the eminent mathematician became in the end fully persuaded of the genuineness of the discovery. He was satisfied on all points, and, having obtained from Lescarbault the particulars of his observation, applied himself to the computation of the orbital elements of the new planet, which had occupied some four hours in crossing the sun's diameter, and the chord it traversed had been duly noted with such accuracy as rough instruments admitted.

Le Verrier found that the mean distance of the planet (now called Vulcan) from the sun (Fig. 1) was about thirteen millions of miles, that its revolution was performed in nineteen days seventeen hours, and that its greatest possible elongation was eight degrees. Further transits of the new body might be expected between March 25th and April 10th, and September 27th and October 14th, and during the few years that ensued it was anxiously looked for by many observers, who, however, utterly failed to see anything of it within the prescribed dates. And it should also be mentioned that M. Liais, in Brazil, states that he was observing the sun at exactly the same time as that when the small planetary body was alleged to have been seen by Lescarbault, but that, though he used a more powerful telescope than Lescarbault, he saw nothing whatever of a strange spot on the sun, and is certain that no such object could have been visible at the time. This threw grave doubt upon the whole matter just at a period when it seemed in a fair way to receive a satisfactory settlement.

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* They had been published in the *Comptes-rendus de l'Académie des Sciences* for 1859.

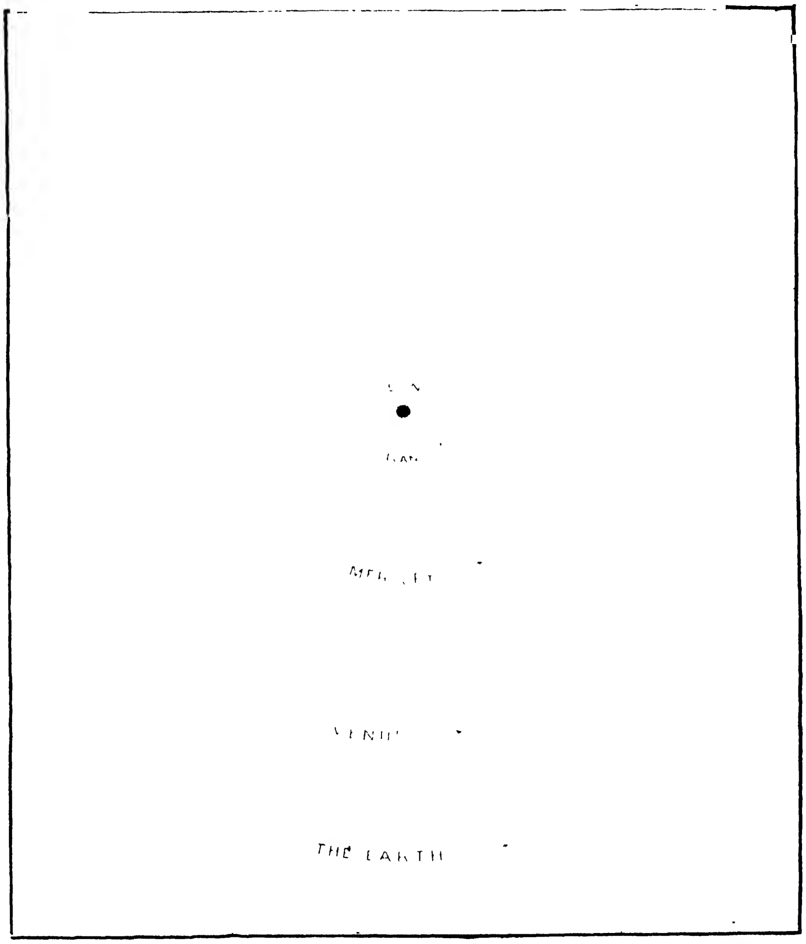

Fig 1.—Relative Positions of the Orbits of Vulcan, Mercury, Venus, and the Earth.

The facts concerning the suspected planet being brought directly under the notice of the astronomical world, caused many observers to inquire whether amongst the records of solar observers there were any notices of the transit of remarkable spots, and a few such instances were soon discovered. On January 6th, 1818, Mr. Capel Lofft, of Ipswich, describes an observation as follows :—" I saw the spot about 11 a.m. with my own reflector, power about 80; with an excellent Cassegrain reflector, made by Crickmore of this town, with about 260, and with a reflector of Mr. Acton's with about 170 It appeared when I first saw it somewhere about one-third from the eastern limb, sub-elliptic, small, uniformly opaque. About 2.30 p.m., it appeared to Mr. Acton considerably advanced, and a little west of the sun's centre, and I think it appeared then six or eight seconds in diameter. I had been able to see no spot on the 4th, nor again on the 8th, and even on the 6th Mr. Crickmore could not see it a little before sunset, though the telescope already mentioned gave him every advantage. Its apparent path while visible seemed to make a small angle with the sun's equator. Its state of motion was inconsistent with that of the solar rotation, and both in figure, density, and regularity of path, it seemed utterly unlike floating scoria. In short, its progress over the sun's disc seems to have exceeded that of Venus in transit. There are two instances, if not three, of comets seen in transit, and this phenomenon seems to have been one."

Fritsch, on March 29, 1800, and February 7 and October 2, 1802, ascribed a rapid proper motion to certain dark spots he observed, but his testimony carries little weight, inasmuch as he frequently attributed such motions to solar spots.

In 1847, early in July, a spot was seen crossing the sun by two observers in London, but though the fact is vouched for on duplicate testimony, its value is in part destroyed by the circumstance that the date was not recorded, and may therefore not have been precisely coincident. Moreover the season of the year to which the records so doubtfully refer precludes the possibility of this spot being a transit of Lescarbault's planet.

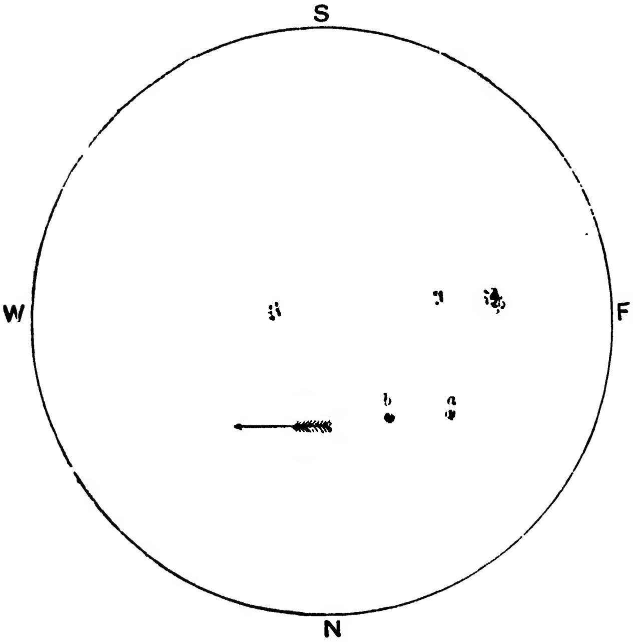

Fig. 2.—Planetary Spot on the Sun, August 1, 1858.

A few years ago the writer received an account of a supposed planet which had presumably been found on the sun on the 1st of August, 1858, by Mr. Wilson, at Manchester. He says:—"I had been watching the motion of a cluster of sun spots coming round from right to left, as they appeared to be in my inverting telescope, during the few days preceding August 1st, and on the afternoon of that day at four o'clock went to my telescope to see if I could discover any changes in the spots referred to. I was astonished to find a perfectly round black spot, free from any penumbra round the edge, jet black, and not like any spots I had ever seen before on the sun's disc. I at once concluded it must be Mercury in transit, and by watching it closely I fancied I could really see it moving, and leaving the cluster of spots on its right. I continued my observations for nearly an hour and a half, until the sun was obscured by clouds, but by that time the small body had advanced from right to left (from *a* to *b* in Fig. 2) not less than 4 or 5 times its own diameter, which I estimated as from $\frac{1}{50}$ to $\frac{1}{60}$ that of the sun. The telescope was a rude instrument of my own make, with a 'simple lens' object glass of $2\frac{1}{4}$ inches diameter, and 75 inches focus, power about 50." This observation obviously refers to an object of considerable size, and much larger than the suspected intra-Mercurial planet. It may have been an ordinary sun spot of rather exceptional type, but the apparent motion of the spot, if real, is difficult to explain on ordinary grounds. The position of the sun's axis with relation to the observer's horizon changes so rapidly that in an hour a marked displacement will be observable in the telescope. A spot which near sunrise appears on the apparent south-east edge of the sun will at noon be placed on the east-north-east edge, and at sunset will have reached the north side of the sun. This will be better explained by a diagram (Fig. 3).

An observer, unless he allows for such apparent motions as arise from the sun's diurnal path across the sky, is likely to attribute erroneous motions to sun spots, though we can hardly say that this will sufficiently explain the remarkable observation by Mr. Wilson above alluded to, because he distinctly states that the positions of the spots varied with relation *to each other*.

On March 20, 1862, another planetary spot passed over the sun. It was seen by Mr. Lummis at Manchester, and his observation supplies one of the best instances we have of this nature. He records that between 8 and 9 a.m. he was struck by the apparition of a spot moving rapidly across the sun. He called a friend's attention to it, and they both remarked its sharply circular form. The apparent diameter was estimated at seven seconds of arc, and it was unfortunate that after following it for twenty minutes, during which he estimated it moved over twelve minutes of arc, his official duties compelled him to leave his telescope, and the completion of the transit was unobserved.

Approximate elements were independently derived from Mr. Lummis's notes by two French computers, who not only agreed fairly well together, but also with Le Verrier's former results, and thus the probabilities of the existence of the new planet were yet further enhanced. Results so distinctly confirming each other could hardly be erroneous, and the question naturally arose how far the original observations upon which they were based could be trusted. Doubtless, they were somewhat rough, and, necessarily so, for the observers had been taken unawares. They had not expected so unique a spectacle as that of a planetary spot on the sun, or they would have been prepared with suitable instruments for its complete and accurate observation. We can hardly doubt that these spots were seen, for to question the veracity of the observers must lead us directly to assume that the scientific world was victimised by gross impostures. In some instances observers might have been a little hasty in ascribing proper motions to solar spots, and we can readily understand that inexperienced persons would be specially liable. Their enthusiasm may have carried them beyond the true appreciation of the facts. The hurried nature of the observation in several instances lends countenance to this idea; but yet, to sum up, it is impossible to explain the best authenticated cases, unless on the assumption of a new planet. It is true that all attempts to calculate the orbit appear to have failed in the sequel, for the predictions, which have been several times made, as to the time when the planet might be again witnessed in transit, have utterly failed. Telescopes have been directed to the sun again and again with the view to capture the errant body, but invariably without success. The repeated examination of the solar disc has, in fact, revealed nothing but the ordinary sun spots. The small, circular, dark spot so eagerly sought for has never presented itself, and there remain the same doubts now as when Le Verrier first announced his conclusions in reference to the existence of the planet.

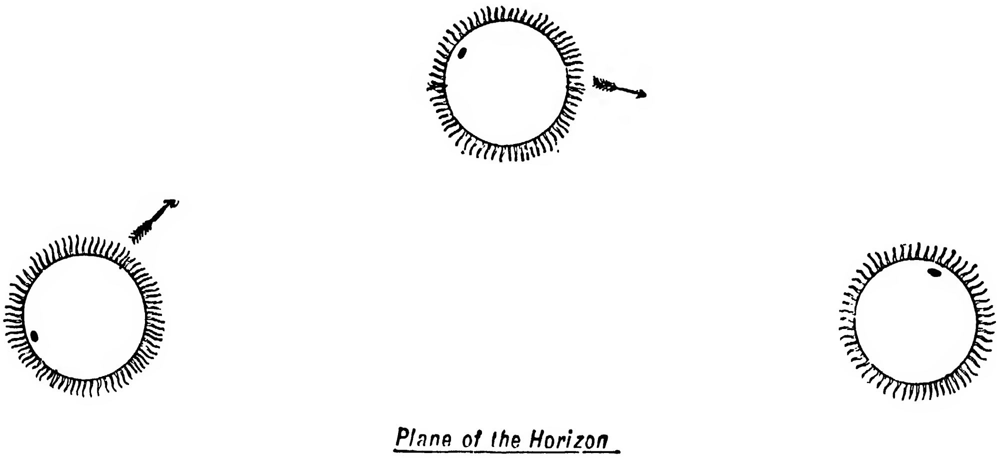

Fig. 3.—Change of observed position in a Sun spot originated by the Sun's apparent Diurnal Motion in the Heavens.

It is very remarkable that it was never seen by our greatest solar observers. Hofrath Schwabe, at Dessau, observed the sun every day, when visible, for more than forty years, yet he records no instance of a planetary transit; and Carrington, Howlett, and others noted for their diligence in recording solar phenomena, have given us no evidence of the suspected body. Their voluminous registers are silent upon the subject. Yet had a planet presented itself upon the sun during one of their searching investigations it must have been detected immediately, and watched with accurate detail. But through all the years during which these experienced observers scanned the sun with devoted pertinacity, and amongst all the well-nigh innumerable host of sun-spots which they examined, not a single instance can be found in which the records distinctly refer to a planetary body in transit, and this cannot fail to be regarded as a fact tending to negative, in the strongest manner, the isolated descriptions which have been adduced upholding the theory of a new planet.

Mr. Hind, in October, 1872, recommended observers to watch the sun on March 24 of the ensuing year; for having analysed the subject thoroughly, his resulting computations led him to infer the probable transit of the suspected planet on that day; but though the sun was closely watched at British and foreign observatories nothing unusual was seen. It is true that an observer at Shanghai telegraphed to Mr. Hind that his "predicted circular spot on the sun had been seen there distinctly at 9 a.m. on March 24," but there was no reference to motion, and the probability is that an ordinary sun spot was alluded to.

In 1879, Prof. Oppolzer, of Vienna, investigated the matter, and from a combination of eight observations of black transitory spots deduced new elements for the strange body, and found that if the calculated orbit were to be relied upon, a transit of the planet must occur on March 18, 1879. But in this case also, purely negative results awaited the observers, so that, in fact, all the computations hitherto attempted have failed to prove truly representative, and to indicate the very essential detail as to when the new planet may be seen crossing the sun. We must evidently await another accidental observation before a reasonable hope can be held out that the subject can be successfully grappled with by mathematicians; and, obviously, there will be a great amount of credit due to those who shall, at last, definitely settle the matter, by firmly securing the evasive stranger, and placing him amongst the series of planets whose orbits and motions have been thoroughly well ascertained.

We have been dealing with the question, so far, as relates to alleged transits of the supposed planet over the sun, but it may be dealt with in another aspect, for its discovery has been hinted as possible during the phenomenon of a total solar eclipse when it might be detected in the neighbourhood of the sun. On such an occasion an unnatural darkness envelops the sky; the planets and brighter stars are visible as at night, and it may be fairly expected that a strange luminous body, if really existing near the sun, would become perceptible at such a time if attentively looked for with the naked eye, and, that failing, with the telescope. But such observations have very rarely been attempted. Those who have had the opportunities have neglected them. The striking phenomena of the eclipsed sun have wholly engrossed them, as they have stood watching its rapidly-varying aspects, and we cannot wonder that, in the face of such an all-absorbing spectacle, no thought has been directed to other observations. At last, however, the spell has been broken. During the total solar eclipse of July 29, 1878, two American observers were alleged to have detected the long-sought planet. Previously to the eclipse, a chart had been carefully prepared of the positions of such planets and stars which might be expected to be visible; and, in addition to these, there was seen a small stellar object near the sun, which, from its position, could not be identified with any known object in the heavens. One of the observers (Professor Watson), well known by his numerous discoveries of minor planets, states that, during the progress of the eclipse, "he found a ruddy star of 4½ magnitude, which, with a power of 45, showed a perceptible disc without any appearance of elongation, as might be expected if it were a comet." He also found another object which he could not certainly identify, and the observations were confirmed by another observer, for the positions, independently assigned, agreed within small limits. Now, at last, the planet seemed to have been discovered, though, in certain quarters, the observations were not considered to be, in all respects, satisfactory. One of the observers, Professor Swift, had found it necessary to modify his statements in several important details, and this had destroyed the reliance and value which would otherwise have been attributed to them. Professor Watson's seemed more satisfactory, though it has been since pointed out that the line between his two stars is almost parallel to, and precisely of the same length as the line between the well-known stars θ and ζ of Cancer, which occupied a closely bordering position to the strange objects he has alluded to. A slight error in the adjustment of his instrument would originate a displacement sufficient to explain the fact that the two stars had been mistaken for new planets, and this is the construction put upon the matter by Professor Peters, who has critically reviewed all the facts. The observers strongly oppose this theory, but while doing so are silent upon the very important point as to whether they saw the two stars mentioned *in addition* to the strange objects they have described. If so, then the opposition fails in its chief argument. In the meantime we cannot but entertain the greatest misgiving that this observation will ultimately prove, like its predecessors, of no real value in clearing up the matter.

Professor Peters has fully discussed the so-called observations of planetary bodies upon the sun, and remarks that they have nearly always rested on the testimony of obscure amateurs. Such objects have never revealed themselves to habitual sun observers, or appeared on the solar photographs which have, during recent years, constituted an item of daily work at several of the chief observatories. He alludes to an alleged observation of a planetary spot of recent date, "which, but for its being identified with one of the ordinary sun spots on the Greenwich and Madrid photographs, would now have been considered a well-authenticated apparition of an intra-Mercurial planet." He then proceeds to refer to the observation by Lummis on March 20, 1862, which Le Verrier had looked upon as one of the most valuable records of the kind, and shows that, according to other observations made at precisely the same time, two ordinary spots were noticed by Mr. Lummis; first one, and then, twenty minutes later, the other, which, he thought, was the same as the first one, and had, therefore, apparently moved in the meantime. The positions of the two spots were such as to have readily originated the mistake, and agree with the description which Mr. Lummis had given.

Thus one of the most valuable observations, as it has been considered, is shown to be vitiated by an error of the most simple character, and, admitting this, we cannot but feel apprehensive of the worthlessness of the remaining instances. It is quite possible that they are all to be explained on other grounds than that of an intra-Mercurial planet. They can hardly have been meteors, because the observed motions were too gradual, nor can they have been terrestrial objects from the same cause. Flights of birds, insects, seeds, or dust particles, are occasionally, no doubt, projected on the sun as opaque bodies in rapid transit, but their swiftness and irregular motion at once distinguish their character. A very interesting observation of this kind was recorded by Capt. Herschel at Bangalore, in India, on October 17 and 18, 1869. At noon on the 17th some dark shadows were noticed crossing the sun, and afterwards some light streaks beyond its border. Their frequency and uniformity of direction attracted notice, as indicating that an unusual phenomenon was in progress, such as possibly the passage of a meteoric stream over the sun. They were watched until sunset, and at seven o'clock the following morning the bodies were still passing in a continuous stream. At noon the observers had obtained the following chief facts of their appearance:—

Their direction is towards about 150 E. of N., but it is almost certain there are two streams. They are not very distant, and their motion is irregular. On the whole, the motion resembles that of floating particles subject to the influence of a mingling of many currents. Their number is anything short of infinity. Their form is very difficult to describe, but ultimately they seemed to take that of a double crescent with a bar across, and wings, or phantom-like appendages, accompanying, as in Fig. 4, *a*. At last one of the objects paused, hovered, and whisked off, and in that instant the observer saw the appearance as in Fig. 4, *b*. There *was no longer any doubt; they were locusts or flies of some kind.* The next morning (Oct. 19) they were still streaming by in hundreds in the same direction. At the time when the above description was written, the *Homeward Mail* contained the news that countless locusts had descended upon certain parts of India.

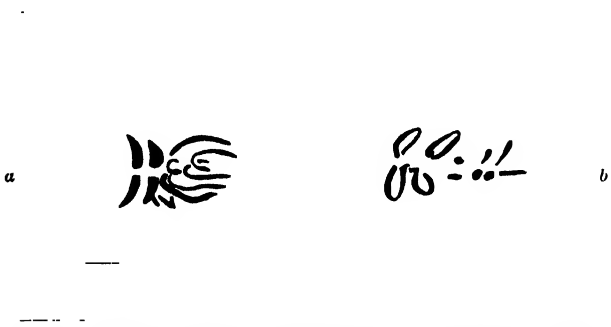

Fig. 4.—Dark Objects seen crossing the Sun on October 17, 18, 1869.

The appearance here referred to will account for other similar phenomena which have been sometimes observed. During the eclipse of Aug. 7-8, 1869, "meteoric bodies were seen to cross the telescope from west to east like bright flakes." These curious objects are capable of the same explanation as that just given above. In such cases the facts cannot be too carefully recorded by those who witness them, and observers should endeavour to avoid undue haste in ascribing to such objects a cosmical origin when they are to be readily accounted for by some ordinary event of purely terrestrial character.

Thus we have seen by what has been said of the facts connected with the history of the new planet that the whole question is at the present time in a most doubtful state. The existence of the alleged planet may or may not be considered probable according to the view we take of the evidence before us. It is certain that nothing definite is to be gleaned from past observations. Mathematicians have laboured unsuccessfully to reduce them to a tangible form, and to make them the basis of trustworthy prediction, but all to no avail. Absolute failure has invariably attended such efforts, and a satisfactory solution can hardly be anticipated until we have further observations to import into the discussion. Meanwhile observers should not abate their assiduity in watching the sun for remarkable spots, and it is most gratifying to consider in this connection that, should a planetary body be presented it will have little chance of avoiding discovery, seeing that at several of the principal observatories the sun is photographed every fine day, and his spot phenomena subjected to an examination in detail. And, moreover, there are numerous irregular observers constantly on the alert to scan the solar surface, so that it is hardly possible a planet could complete its transit without being seen somewhere.

The comparative frequency of such transits must obviously depend upon the planet's inclination of orbit. If a small value represented this, then the planet would often be projected upon the sun; indeed, according to Professor Oppolzer's computations, a transit should take place every year in March and October. But, on the other hand, if the new planet showed a considerable deviation from the plane of the ecliptic we should seldom be enabled to witness such phenomena, for as the planet arrived at conjunction with the sun it would pass either above or below that luminary, according to circumstances. The probabilities are that transits are somewhat rare. If they were of annual occurrence it would be difficult to account for the fact that they so frequently eluded detection, unless we attribute to the planet a much smaller diameter than that commonly assigned. Possibly the new body is more minute than Mercury, and, by analogy, one might expect it to be so, for Venus, lying nearer the sun than the earth, is inferior to it in magnitude; and Mercury, nearer than Venus, exhibits another diminution in point of size. If this consecutive decrease extends to the new planet, then it could only be an object for very powerful telescopes, and we can therefore the more readily understand how it has escaped certain detection for so many years.

A FEATHER.

By Hans Gadow, M.A., Ph.D., New Museums, Cambridge.

It requires no scientific knowledge, and only the most superficial observation, to know that birds' feathers vary infinitely in shape, hue, and glory. We have the gaudy plumes of the peacock, and the more sombre garb of his mate; the black covering of the raven, and the snowy plumage of the ivory gull. But when feathers are examined from the anatomist's point of view, the bright hues which give them character, and even the endless forms of the bird's covering, become altogether secondary, and, as it were, trivial matters of detail. The study of the development of feathers shows that they are identical in origin, and that, however much they may differ in their adult state, they have certain broad invariable features in common. First, then, let us examine the anatomy of a feather.

The hard substance of the feather—that is to say, the part which resists alike wet and putrefaction—belongs to the same category of horny productions of the animal body as hairs and finger-nails.

We can separate a full-grown feather—such as that of a fowl's back—into three different parts (Fig. 1).

First, there is the quill, or *scapus.* It is the strongest part of the feather, and consists principally of a long narrow cone, the basal part of which, called the barrel (*calamus*), and out of which pens are, or were, made, is hollow, round, transparent and colourless; whilst the upper and far longer part, the proper shaft (*rachis*), is more or less quadrangularly compressed, and filled inside with a pithy substance, very similar in appearance to the white and light interior of an alder twig. This quill carries the barbs (*rami*), which form the second important part of the feather, as they, although small, number several thousands in a large feather, and compose, by their standing so closely together, a compact flattened plane, which we know as the webs, or vane (*vexillum*).

These branches lie opposite to each other on two sides of the shaft, and consist of flat *lamellæ*, or bands, gradually tapering towards the margin of the feather. They lie with their flat sides one on the top of the other, and are so placed that one edge looks upwards and outwards, while the other looks downwards, and towards the body of the bird.

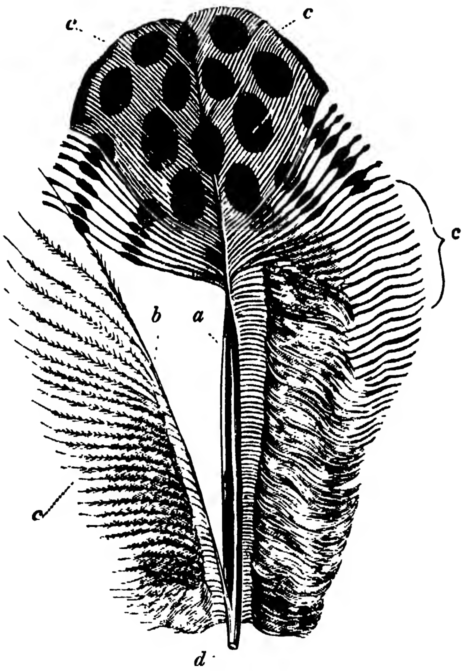

Fig. 1.—Feather taken from the back of an *Argus giganteus*: *a*, the Shaft; *b*, Aftershaft; *c*, Branches composing the web: these branches being taken away from the one side both of the shaft and the aftershaft; *d*, part of the Barrel. Natural size. (*After Nitzsch.*)

Thirdly, there are the *radii* (Figs. 2, 3, 4, and 5).

They have the same relation to the rami that the latter have to the shaft, so that each ramus with its radii is a miniature feather in itself; only the manner of their arrangement is different—the radii attached to the upper edge of the rami pointing in the direction of the tip of the feather, while those issuing from the under edge are directed backwards and outwards. Near the base they are also flat *lamellæ*, ending, however, in a very fine point. The number of radii on every ramus is very large, and this can be seen with the naked eye. They are the tiny things seen between the branches of the web when we hold the latter up against the light, and carefully try to detach them from one another. In attempting to do this, however, we at once remark that we cannot so easily separate the rami from each other, but that they cling to each other as if they were glued together. This is the result of the peculiar structure of the radii, which, as we shall soon see, are of very different shapes.

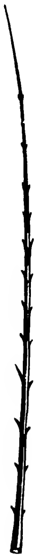
Fig. 2.—One radius of a Hawk's Down. (*Largely magnified.*)

In most cases there issue from the outer side of those radii which are directed towards the edge of the whole feather additional, very thin, thread-like lashes, which we can see only under a strong power of the microscope. These are called by the scientific name of *cilia* (Figs. 2, 3, 4, and 5). Their greatest development takes place, on the average, in the middle part of the radii, where some of them are bent at their tips like hooklets, called on this account *hamuli* (*h*). These hamuli are of very great importance, in spite of their surprising smallness; because their tiny hooklet-shaped tips, clasping round the somewhat thickened edge of the next radius, fasten on to the latter, and thus hold all the radii together (Fig. 5). By this arrangement a double advantage is effected. Firstly, the neighbouring radii, and through these also the rami, are bound, or combined together, to a flat and broad plane—the so-called "web"—by means of which the bird can cause a pressure on the air, and is enabled to rise into the air, and to fly; secondly, the whole web is now elastic, to a very great extent, as by the motion and bending of the web all the innumerable single hooklets slide up and down on the edges of the radii as in a hinge, so that a tearing or loosening of the radii becomes almost impossible.

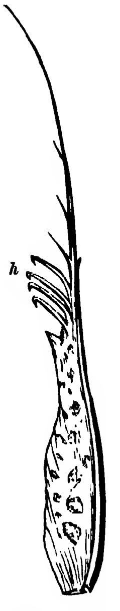

Fig. 3.—Radius from Ramus of a Pigeon's Quill.

The cilia themselves exhibit, in the several kinds of feathers and in the different families of birds, very great variations in shape, as well as in their number. The total number of the cilia and hooklets on every radius amounts, on an average, to a dozen, half of this number being transformed into hooklets. Again, in several places, and in different kinds of feathers, even on one and the same bird, the cilia consist simply of quite short points—as, for instance, near the tip of a feather off a duck's back. Others, again, have the shape of very small irregular cups, or, especially on the tips of the downy feathers, they are represented merely by small knots. Accordingly, some authors make a distinction between simple, knotted, and branched radii.

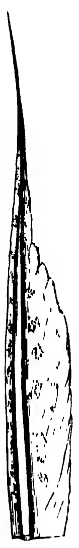
Fig. 4.—One radius taken from the same Ramus, but from the side pointing towards the tip of the Feather, showing the Cilia and Hooklets. (*Greatly magnified.*)

It may here be observed that these cilia, with their variations, the little hooklets, are not, as formerly was the general opinion, equivalent with the rami, or even the radii, but that they are to be looked upon as excrescences of the surface of the radii; because with the help of a strong microscope we find that some of the cells of the radii have a more rapid and larger growth than the others, and so, by their growing larger and longer, give rise to the rough surface of the radii, and to the several shapes which are known as knots and hooklets.

Another part in many feathers is the so-called after-shaft, or *hyporachis* (Fig. 1). As it consists of a shaft which sends forth again smaller branches in two opposite directions, it seems like a separate feather by itself. The whole after-shaft springs off at the inner side of an ordinary feather at the place where the barrel goes over into the pith-containing and web-carrying shaft, just where the so-called "soul" of the feather sticks out (this region of the feather being known as its "nabel"). Such an after-shaft shows its greatest development in some of the ostrich-like birds; in the covering feathers of the Cassowary, Dromaeus, and Apteryx it is of the same length, and exactly of the same structure as the real feathers, so that every feather taken from the back of such a bird seems to be double.

In most of the other birds the after-shaft is very small—as, for instance, in domestic fowls, ducks, geese, waders, and singing birds. Many other birds—as for instance, the owls, cuckoos, pigeons, cormorants, &c.—want the after-shaft entirely. It is, moreover, never found on the great quills of the wing and tail (Figs. 9, 10). Let us now, for curiosity's sake, count up of how many of all these parts mentioned above one single feather may consist. We take, for example, as I have one just handy, an eagle's quill, the web of which is fifteen inches in length.

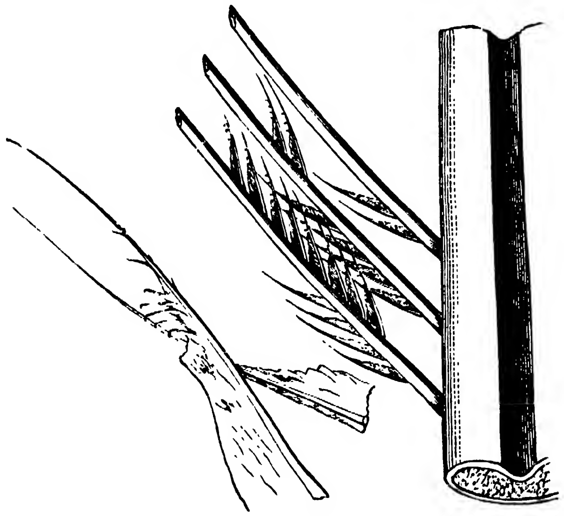

Fig. 5.—Under view of a part of the Shaft of a Quill, with the basal parts of three Rami, the Rami showing ten radii as figured in Fig. 3, and ten radii as seen in Fig. 4, magnified. In the corner are seen two radii in their natural position, showing how the Hamuli of one radius clasp round the edge of the radius of the neighbouring Ramus. (*Much magnified*)

On the inner web I count about eleven hundred rami; on the outer web about nine hundred. From each side of one of the longest rami of the inner web issue about fifteen hundred pairs of radii; consequently, on that single ramus there are at least six thousand radii. The rami at the different parts of the web being of a different length, we will accept as the average number of the radii of every ramus about 2,000 pairs, or 4,000 single radii.

On every ramus of the outer web there are about 600 pairs or 1,200 single radii. Every one of the latter, again, sends out about ten cilia and hooklets on the outer web, as well as in the inner one, with this result:—

Inner web has 1,100 rami with 4,000 radii equal to 4,400,000 radii.
Outer web has 900 rami with 1,200 radii equal to 1,080,000 radii.
The whole web of 2,000 rami has thus 5,480,000 radii, with the cilia and hooklets equal to about 30,000,000.

So this single feather contains about two thousand rami, five millions and a half of radii, and the surprising number of more than fifty-four millions of cilia and hooklets! The rami and radii being added, it consists, roughly speaking, of sixty millions of parts. How large, then, will be the number of these things in one of the long and beautiful feathers of a bird like a peacock may be imagined, for, in fact, they exist in numbers almost impossible for us to estimate.

A bird is born unfeathered. The feathers grow after it emerges from the shell; for the fluffy down with which the skin of the young chick is clothed is but the promise of the covering of its maturity.

How, then, is developed such a complicated and delicate structure as a feather, which contains, at the same time, so much strength and elasticity? This leads us to inquire into and follow its growth from the earliest stages to the perfect form.

The commencement of the growth of a feather is surprisingly simple. Let us take for examination the egg of a young fowl, or a duck, after it has been sat upon by the mother long enough for the embryo, or young animal, to be developed by her animal heat from the substance of the egg.* Let us look at the end of the first week at the still quite soft skin of the embryo. In birds, as in mammals, the skin consists of two principal layers; first, a very thin horny layer, which surrounds the whole of the bird externally—this is known as the *epidermis;* secondly, a thicker, softer, and more tenacious under-layer, immediately covering the muscles of the body—this is called the *cutis*, or leathery skin. The cutis is very juicy, and full of blood, and forms the substance which, when tanned, we ordinarily know as *leather.* Between this cutis and the upper layer—viz., the epidermis—exists another soft and juicy layer, which belongs to the epidermis, or, to speak more correctly, the epidermis belongs to this second layer; because this middle layer (*rete Malpighii*) really forms the epidermis, being the part which renews the latter when it is worn off by daily friction. Such a wearing off of the epidermal layer is seen in the scurf which falls from our heads in daily life. The *rete Malpighii* itself consists of a layer of small cellulæ, visible only under the microscope.

But now to return to our chick. Its whole skin gets in many places small irregularities of surface or elevations which, gradually becoming bigger and higher, form small pimples (*papillæ*). The whole thing is caused by a swelling of the cutis and the *rete Malpighii.* Very soon, however, the base of this small lump sinks deeper, carrying with it the surrounding epidermis, and so causes a growth to form, from the middle of which projects the first beginning of the future feather, the so-called *pulpa pennæ*—or " feather pulp."

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* "The History of a Hen's Egg:" "Science for All," Vol. II., p. 195.

When examined under a strong power of the microscope, a longitudinal section of the whole organ would appear as shown in Fig. 6. The whole is the papilla, with the pouch-like depression, and all is covered by the epidermis (*e*), underneath which is the layer of cells of the *rete Malpighii* (RM), and below that the true cutis covering the muscles (M). In this cutis are seen an artery (A) and a vein (V), which are the blood-vessels which supply the future feather with blood—*i.e.*, the means of nourishment. The elevation (P) is the pulpa, the real germ of the feather.

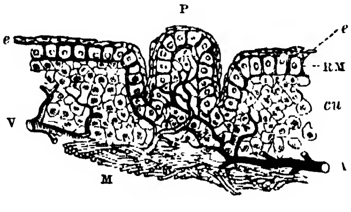

Fig. 6.—Longitudinal or vertical Section: the whole is the Papilla, with the pouch-like depression, covered by the Epidermis (*e*). RM, layer of cells of the Rete Malpighii; *cu*, Cutis, or true skin; M, Muscles; P, Pulpa, or germ of the growing feather; A, an Artery, and V, a vein in Cutis that supply the future feather in the blood. (Magnified).

This pulpa now begins to change its simple form. The basal portion (that nearest the flesh of the bird) becomes, as it were strangled, and gets an onion-like shape (P_2 in Fig. 7), whilst the upper part (P_1) increases in length, and stretches upward more and more. The surrounding cells (RM) of the *rete Malpighii* multiply, and the latter grow also in length, by dividing themselves longitudinally and transversely, and then getting hard and horny, like our finger-nails. Then every one of these series of cells grows to a fine horny thread, which begets, moreover, on the sides smaller threads, only visible with a lens, perforating the epidermis. We now see sticking out of the top of the "pimple" a little tuft of about a dozen bristles, like a small paint-brush. The outer layer (the epidermis) is torn by this process, and falls off in small scurfy pieces at the time when the young chicken comes out of the egg.

A longitudinal section of such a young primitive feather exhibits the following aspect (Fig. 7) :—

F is the small feather-brush; *e*, the falling-off scurf of the epidermis; RM, the two layers of the mucous layer, or *rete Malpighii,* like the finger of a glove drawn back half-way into the glove; P, the upper part, and P_2, the basal part of the pulpa, in which the artery and the veins are seen.

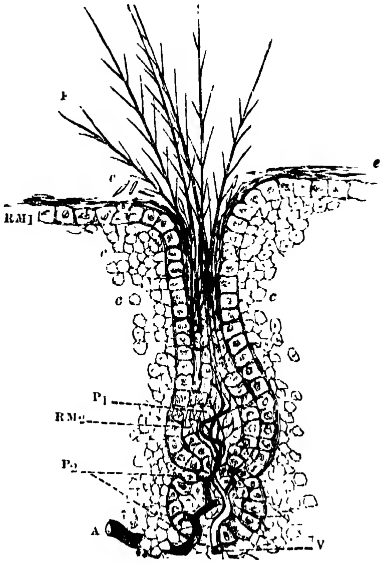

Fig. 7.—Longitudinal Section of a growing downy feather of a bird in the shell. The bristles have pierced the Epidermis (*e*), which falls off in small scurfs. RM, Rete Malpighii; *c*, Cutis; P_1, P_2, Pulpa; A, V, Artery and Vein; RM_2, the inner layer of the Rete Malpighii, formerly the outer layer of the pouch, before being so deeply pressed down (Fig. 6).

Now, such feather-brushes being distributed over nearly the whole surface of the body, the young bird, when it emerges from the egg, has got a soft covering, which serves as its first protection against the cold and wet. However, such a simple covering is not sufficient for very long, since the young bird, as it increases in size, cannot any longer be covered and warmed by its parents; besides this, it will have to fly, and for this purpose, it wants large and strong feathers.

The small, tiny feathers, therefore, the growth of which we have examined already, after they have fulfilled their purpose, fall out, the artery ceasing to carry any more blood into the upper part of the pulpa, and so consequently the feather-brush dries up and dies.

The basal, onion-like half of the pulpa, which had become separated from the first foundation (seen in Fig. 7), begins to grow, and becomes so long that it sticks out to a considerable distance from the body, and pushes the first downy feather-brush off (Fig. 9). At the same time the surrounding cells of the mucous layer grow and multiply in number very quickly. At first branches develop out of the uppermost cells quite similar to those which we have seen in the first covering of the nestling. These branches stick out of the skin, and form the top of the new definitive feather. The outermost cells of the mucous layer transform themselves into a horny, thin, and transparent sheath for the young feather. Later on, the feather having grown larger, this sheath bursts, and falls off in pieces. At this stage the bird is now in the condition known to every one as "pen-feathered," and when it shakes itself the scurfy scales fall off in every direction. Then the pulpa grows more and more in length, and forms that part, which, full of blood and nourishing juice, and of a reddish-blue colour, is the basal half of the not yet fully-grown feather. A transverse section of this part would give us the appearance shown in the cut below (Fig. 8).

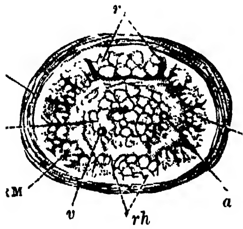

Fig. 8.—Transverse Section of a growing Feather, at about the middle of Fig. 9, where the letters *sh* are put: *e*, the Epidermis surrounding the whole pouch, immediately adjoining the layer of cells of the Rete Malpighii (RM), these cells once more surrounding the Pulpa (P); *r*, the collection of cells which go to form the shaft; *rh*, those cells which go to form the aftershaft; *v*, *a*, sections of the Vein and Artery. (Magnified.)

At first one of the marginal cells increases considerably in bulk at the expense of its neighbours, and occupies the greater part of one side, usually the side nearest the body (*r*); it ultimately transforms itself into the strong shaft of the feather, giving a base for the rami with their component radii, &c. These rami originate from the remaining marginal cells of the *rete Malpighii* (RM), and form, as we have shown above, the web of the feather. When the web has grown to its full length, the marginal cells cease to produce rami, and amalgamate into a strong horny ring (as it appears in transverse section). It is this part which is called the "barrel" of the feather.

Everywhere, when the shaft with its rami is perfected, the function of the pulpa ceases, the vessels inside it dry up at its summit, and as, at the same time, the juice contained in the pulpa is used up, the pulpa naturally gets shorter, and retires upon itself towards the base of the feather. Only the outer shell of the pulpa remains, resting like a small cap upon the summit of the pulpa, and as the latter retires little by little at certain intervals, a succession of these small transparent air-containing caps is formed inside the barrel, known as the "soul" of the feather. This "soul" is familiar to everybody who has cut a quill, as it has to be withdrawn before the pen will write (Fig. 10).

Finally, when the feather has reached its full size, it is attached to the skin by only a very small portion of it, the pulpa having contracted to its original onion-shaped bulb. The feather is now perfect.

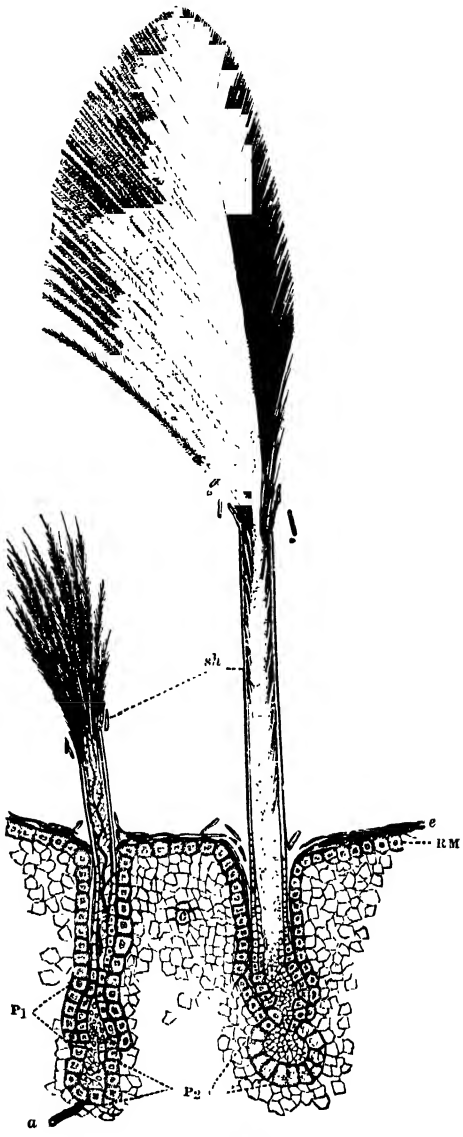

Fig. 9.—Longitudinal Section of two growing Feathers, the smaller one in a stage where the bristles or branches of the tip of the young feathers have just pierced through the broken and partially split-of
P_1 and P_2, the t
supplying the Matrix of the young feather with blood. The barrel of the feather not yet developed. (Magnified.)

The beautiful and often surprisingly magnificent colouring of the feather is derived from pigment, which is collected in the *rete Malpighii*, and is probably also generated therein.

We see the same arrangement in the colour of the different races of mankind. The black colour of the Negroes, the Papuans, and the aborigines of Australia, the coppery-red of the American Indians, the yellow of the Mongols, and the brown of the Malays, is produced by black, red, yellow, or brown pigment cells, existing in the mucous layer of the *rete Malpighii*, and shining through the transparent epidermis. In Europeans, however, this layer contains no pigment whatever, but the blood and flesh shine through the upper skin, and produce the rosy whitish tinge characteristic of their skin.

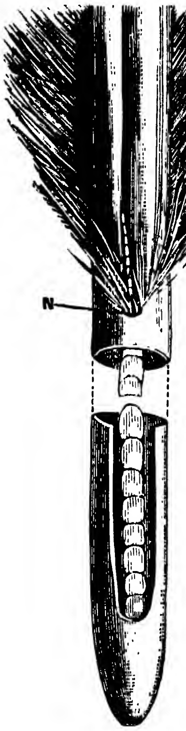

Fig. 10.—Basal part of the Quill of the Bearded Eagle (*Gypaetos barbatus*). The barrel is cut open, showing inside the so-called "soul ' of the feather sticking out at (N) the Nabel. (Natural size.)

When the feathers are abraded or worn with use, or when the bird gets its winter coat or its breeding-dress in the spring, a necessity for developing new feathers arises. Then the small pulpa (P2) revives, new juices being supplied to it by the artery, and, increasing once more in length, again goes through the process we have described above, and pushes out the old feather exactly as in its infant stage it got rid of the original downy plume. This process being carried out in many feathers at the same time, the bird "moults." Again, when a feather is torn out of a bird at any other time than the moulting season, the pulpa is always ready to supply a new one. Thus it happens that, when one of our pet birds loses a feather, or even if one pulls out its whole tail by accident, we have the comfort of knowing that in a few weeks it will develop a fresh and, perhaps, even more beautiful plumage (Figs. 9 and 10).

A few words may be now devoted to the different kinds of feathers. According to their structure and the different parts of the body on which they are found, we may distinguish several kinds of feathers, which, while not strictly different from each other, often show, even in one and the same bird, all kinds of intermediate forms.

Firstly, there are the downy feathers (*plumulæ*). These are rather short, fine, and generally white, with a weak shaft, but have comparatively long and very thin rami and a few radii, though they generally want the cilia and hamuli. These plumes, known as down, are situated in the fully-grown bird between the "contour" feathers, which we shall describe further on. They are entirely covered by the latter, and are thus not visible from the outer surface of the body. Their exclusive use is to provide the bird with a warm covering; they are therefore most developed in the swimming birds, especially in those which live in cold climates. To us they are of great use, as we use them for filling our coverlets and pillows; those considered the best and most in demand being the "down" of the Eider duck (*Somateria mollissima*).

The first covering of the nestlings is also composed of down-like feathers, and not before the lapse of a considerable time do the young birds get true feathers, like those of the parents. These nestling plumes are of a great scientific interest, as very possibly they indicate the remnants of a former state of primitive feathering, showing that the birds of former periods were covered simply with feathers more like those which are now seen merely in the first plumage of the young ones.

Naturalists have acknowledged, as a law of universal value, that the young of animals, especially when they are in an undeveloped state, differ in many points from their parents, and that these differences point to a state of lower organisation resembling that of their ancient progenitors. Thus by the appearance of the young animals we are led to suspect their probable relationship. Accordingly many naturalists have used the feathering of birds and the different conditions of the nestlings at their birth as means of classification, and have divided them into two great orders, called *Ptilopædes** and *Psilopædes*.† Thus the chickens of the first order, the *Ptilopædes*, when hatched, are covered with down all over their body, and are able to supply themselves with food from the moment of their exclusion from the egg; whereas, the second order, the *Psilopædes*, are hatched without any down upon them, and are brought into the world naked, helpless, and blind, depending on the care of their parents for a supply of food and warmth, until they become strong enough to shift for themselves. A familiar example of a psilopædic nestling is seen in the sparrow, canary, and thrush, while the chicks of the domestic fowl or duck, of a coot or a moorhen, are illustrations of the ptilopædic birds. A young coot or moorhen, which, when hatched, looks like a tiny ball of black down, will, on the approach of danger, take to the water at once, and we have more than once found the nest with eggs partially hatched, with the bills of the little ones peeping through the shells, but none of the other nestlings in the nest itself: they had all swum away, or hidden themselves among the reeds.

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* From the Greek words *ptilon*, a downy feather, and a child, or young one.

† From *psilos*, naked, and *pais*.

This kind of classification, however, has not met with universal approval by zoologists; for though the differences of these two groups of birds are very great, the birds of our own era exhibit too many exceptions to the rule. Thus, for instance, although the birds of prey, when hatched, are covered with a rather thick downy covering, they are helpless and blind at birth, and cannot leave their nests. Once more, the young gulls are hatched with a thick downy covering, but sit for a long time in their rudely-formed nest before they make an attempt to take to the sea.

A very remarkable exception to the state of development in which certain birds leave the egg is seen in the talegallas and the megapodes. The latter, to which the mound-building *Megapodius Freycineti* belongs, live in Australia and the Moluccas, and as the eggs are very large, the hen does not sit at all, but buries them in the black lava sand by the shore. The sand is then warmed by the hot tropical sun, and loses but little of its heat by night, and thus the eggs are hatched from the heat of the sand—this temperature being almost the same as the blood of the bird, viz., about 104° Fahr. The young megapodes, however, leave the egg neither in down nor yet quite naked, but with feathers over their body, and wings sufficiently developed for flight.

Still more wonderful is the talegalla bird, found in New South Wales. We have watched in the Berlin Zoological Gardens a pair of these birds, and observed how the male in the breeding period collected with its feet all the available moss, withered and rotten leaves, small branches and earth, and built with them an immense heap. This heap he continually increased until it reached a height of six feet, with the diameter of not less than ten. He then made deep holes in different parts of this mound in which the hen then deposited her eggs. For many weeks nothing more was noticed than that the cock occasionally inspected the heap, when he must undoubtedly have turned the eggs. The heap itself showed a rather high temperature from the fermentation of the rotten leaves and other fermentative substances. This peculiar attempt had been given up by the officers of the gardens as hopeless, as they supposed that the climate was not fit for such kind of hatching, when one morning the keeper observed a young fowl crawling out of the heap, and saw to his greatest astonishment that this chick immediately flew over the neighbouring fence. There then arose a hot chase in the "Thiergarten" by the alarmed keepers, after that wonderful bird, until they got hold of the megapode chick. During the next days several other chickens were found, one of them having been unable or not strong enough to pierce the heap; and so it was found suffocated.

One might suppose that these birds have never had any down covering at all, since they leave the egg fully feathered. But more recent inquiries have shown that the young megapodes, as well as the talegallas, have had down before being hatched. This downy covering is much the same as in the ordinary domestic chicken, but gives place to the new feathers, which become developed and push the down off before the bird leaves the egg, and thus the first moulting takes place already within the shell.

This is again a very remarkable example of the way in which the young of animals repeat in succession all the different stages of development through which their progenitors have gone; for without this presumption of inherited peculiarities, the downy state within the egg would be as inexplicable as it is useless.

But we have, perhaps, spoken at too great length about the down. We have now to treat the most important of all feathers, the so-called "contour-feathers"—those, in fact, which are ordinarily known as "feathers." They are distinguished by a strong barrel and a long shaft, armed with a double web emanating from its opposite sides; the down, on the other hand, has branches projecting equally all round, like the branches of a small fir tree.

They are called "contour feathers" because they are on the outside, and give the visible shape or "contour" of the bird. These are the feathers exposed to the light. They often possess the well-known brilliantly variegated colours, and are therefore of the greatest importance in determining the species of birds. These "contour feathers" are of several kinds. First, there are the ordinary clothing feathers. They are generally short but comparatively broad and more downy near the barrel; they form the covering of the head, neck, breast, back, and the under part of the body. It is generally only the tips of these feathers that are coloured, whilst the other parts are grey, whitish, or indistinctly marked.

The second kind of contour feathers are those which serve for flying, and are generally long and stiff—the so-called "quill-feathers." Those which are situated on the wing are called *remiges*, whilst those of the tail are the *rectrices*, because they help to *direct* the flight of the bird through the air; as the tail, which generally consists of from ten to eighteen feathers, can be closed or spread out like a fan, and turned either to the right or left like a rudder. In good fliers—as, for example, birds of prey, pigeons, swallows, &c.—the tail is very long and well developed. In bad fliers, on the contrary—waders and swimmers, for instance, the tail is short. Finally, in the ostrich, which does not fly at all, it is quite neglected, or developed for mere ornament.

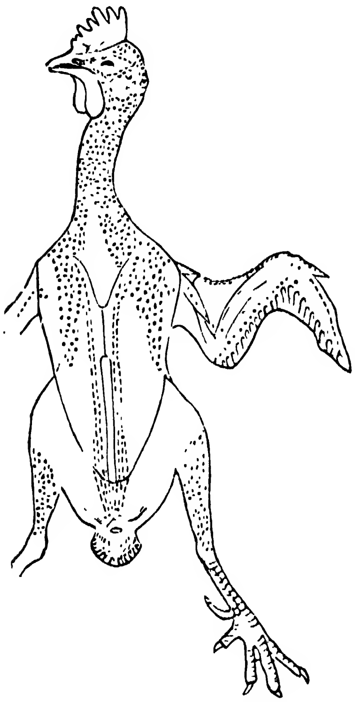

Fig. 11.—Feather tracks on the under surface of the body of a Cock (*Gallus Bankiva*). (After Nitzsch).

Intermediate between these two kinds of feathers—those for covering and flying—there is a number of others, all of which have special names; but to describe would lead us too far. In addition to the magnificently coloured feathers of some birds, as the peacock, we need only mention the most striking variations of the "covering-feathers." To these belong the almost entirely ornamental and remarkably pretty and long feathers of the back of the head of the male heron, the crown-pigeon, &c. The beautiful feathers of the bird of paradise, so often carried on the ladies' hats, are not the quills of the wing, but highly developed and transformed feathers of the breast. So, also, those which compose the "bow" of the peacock are not tail feathers, but its extraordinarily developed covering feathers. The wing-feathers of the African ostrich have lost their character as remiges (rowing feathers), and have become the well-known waving plumes, whilst those of the wings of the penguins, which only dive and swim, have turned quite small and scaly. The remarkable, bare, stiff, and round points in the cassowary's wings are feathers whose whole development is confined to the quill—the web part being entirely absent. In this manner, also, the eyelashes and the bristles on the bills of numerous birds are explicable; they still show, but only at their base, the remains of a former web, and the presence of this web proves that they are to be considered as feathers and not hair, as was formerly supposed.

We have now only to describe the distribution of feathers over the body of the bird. In only a few birds—as, *e.g.*, in the cassowary and the penguin—are the feathers equally distributed over the whole body, leaving no bare spots whatever, except the bill and feet. In almost all other birds, it is found, on examining the body when plucked, that many parts are entirely destitute of feather pores; these places being covered by the overlapping of the feathers of the neighbouring parts of the body.

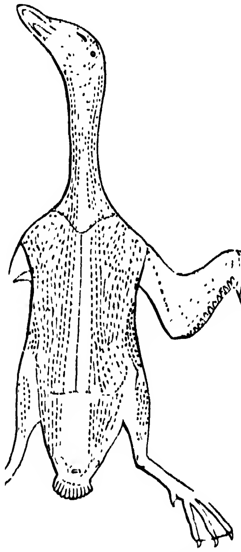

Fig. 12.—Feather-tracks on the under side of the body of a Duck (*Anas Penelope*). (After Nitzsch.)

The proportion of these naked parts, called *apteria*, to the feathered ones (*pterylæ*), is important for the systematic classification of birds, as has been pointed out by Dr. Nitzsch, the discoverer of this arrangement. According to the different parts of the body where these "feather-tracks" are found, these tracks themselves have different names—as, for instance, the neck, shoulder, and belly-tracks. But as a more minute description of the immense variety of these marks would lead us into too lengthy a discussion, we shall simply content ourselves at present with a few sketches of the best known birds, by way of illustration (Figs. 11 and 12). It may, besides, be easy for our readers to verify these remarks by reference to the birds in question.

THE WANDERINGS OF A PEBBLE.

By Professor T. G. Bonney, D.Sc., F.R.S., F.G.S.

A GREAT part of the visible crust of the globe is made up of stratified or bedded rocks. To a large number of these—to the greater part, in fact—the name of klastic or fragmental rock is given, because they are composed wholly, or almost wholly, of the fragments of other rocks. In some cases—probably in many cases—these fragments have done duty again and again. A grain of sand,[*] derived originally from some part (most likely that which was coarsely crystalline, and so not among the easiest attacked) of the igneous crust of the primæval earth, may have been first embedded in a sedimentary deposit myriads of years since, perhaps before a back-boned animal swam in the seas or trod upon the land. This grain, after long resting—after undergoing the operations of chemical forces while buried deep in the earth—may have been again upraised, again displaced by the action of heat or frost, of rain or river, have been again hurried along by the stream, and again entombed in some new deposit. And this process, for aught we know, may have been repeated a dozen times. In an eloquent passage in "Modern Painters" (Part V., ch. xvi.) Mr. Ruskin describes the thoughts which would have been possible to a "little flake of mica sand, hurried in tremulous spangling along the bottom of the ancient river, too light to sink, too faint to float, almost too small for sight, and laid at last (would it not have thought?) for a hopeless eternity in the dark ooze," yet fated to become one day part of the material of an Alpine pinnacle, against which the winds should rage in vain, beneath which "the snowy hills should be bowed like flocks of sheep, and the kingdoms of the earth fade away in unregarded blue." This, which may be true sometimes of the mica flake, is very often true of the grain of quartz sand; for of all the minerals known to us which commonly compose the crust of the earth it is the hardest, the least frangible, the most insensible to chemical action.

In the future of geological science the source of the constituents of a sedimentary rock will be a matter of more careful inquiry than it has been in the past. If we can identify a pebble[†] or a grain of any mineral in a klastic deposit with the rock from which it has been derived: if there are peculiarities in each which render it improbable that there should be any hesitation about referring the one to the other, we are in possession of a number of facts bearing upon the physical geography of the world in a past epoch. From the condition of the fragment we can infer the nature of the agent which transported it; its relative position tells us the direction in which that has acted; its existence shows us that the parent reefs or ridges were at that time exposed to denudation. To make this identification may some day be possible, indeed, is now sometimes possible in the case of the finer fragments of rock; but it is often comparatively easy in the case of the larger. The present paper is an attempt to trace back one such fragment to the source from which it has been derived.

Persons familiar with the Midland counties of England will remember that over a large area in them the common rocks are red marls, sandstones, and gravels. The last-named lie low down in the group called, by the older authors, a part of the New Red Sandstone, by the later more commonly, and at present, the Triassic series. These gravels, which often become sufficiently indurated to be conglomerates, bear the name of the Bunter Pebble Beds; the word Bunter being of German origin (for beds identified with this series occur in that country), and meaning parti-coloured. They may be traced, as has been described by Professor Hull in his valuable "Memoir,"[‡] from the Cheshire and Lancashire coast to Central England, and thence round the southern extremity of the Pennine Chain, northwards to the Vale of York.[§] The character, indeed, of the deposit varies from one part to another. In the Cheshire district it is thickest, though the pebbles are smaller and less abundant; they are most numerous and larger in the parts around the south of the Pennine Chain.

Let us, then, suppose ourselves on some outcrop of the Bunter soil in the latter district. There is none more characteristic than the moorlands of Cannock Chase. The pebble beds occupy a considerable area of this region, a hilly upland or plateau, with a barren gravelly soil, in many parts still untouched by the plough and covered with heather and furze. The pebble beds here are about 300 feet thick, and beneath them, commonly at no great distance, lie the coal measures. There in many places shafts have been sunk and collieries opened, much to the detriment of the scenery; in fact, between the miner and the farmer the moorlands of Cannock Chase will in another generation be a thing of the past. These beds consist of a reddish hardened sand or sandstone, sometimes crowded with pebbles, sometimes almost free from them, and then forming rather thin and irregular bands in the conglomerate rock. The coloration of the sand is due to a coating of iron peroxide (rust), not to any tint in the quartz grains themselves. These sands, variable in colour from red to white, form the greater part of the Bunter series, the pebble beds being the more local members. The pebbles vary in size, from no bigger than nuts to about six inches in diameter. On the northern edge, however, of Cannock Chase the majority of them are about three or four inches in diameter; usually they are well rounded, rather oval in form, and smooth on the exterior. Seating ourselves upon a heap thrown out from a pit, and broken for mending the roads, we may begin to study their mineral character. A brief examination shows us that the bulk of them are only varieties of one kind of rock, but still there is an intermixture of others, though they are less numerous. Here, for example, is a bit of carboniferous limestone, generally less well rounded, which looks as if it had come from the Derbyshire hills. Here is another of chert, showing casts of the stems of small crinoids, probably from the same locality. Here are pieces of rotten granite, or perhaps schist; here (in better condition) some felstones; here a few black, cherty-looking rocks, which some geologists have called Lydian stone: these we throw aside into one heap, leaving behind those which appear to be mainly composed of quartz. On looking through the latter more carefully, we find that we may at once separate a number of pebbles of vein quartz, leaving still behind a large quantity, which are all varieties of the rock called quartzite.* These we might at first feel inclined to group together as from one and the same locality, but closer study shows us that we have really got two distinct rocks mixed: the one a kind of hard grit, sometimes rather loose in texture, with specks of decomposed felspar, not very highly altered; the other almost all pure quartz and very highly altered, so as to be sometimes so compact that the edges of the component grains appear quite fused one into the other. In the former we find fossils, though but rarely, and these show the rock to belong to the Llandovery series (the lowest part of the Upper Silurian); the latter show no signs of organisms, except now and then we may possibly discover the indication of a fair-sized worm-burrow just enough to prove that life in some form or other existed when the rock was first deposited as sand. These last pebbles vary considerably in colour; some are shades of pale grey, others pinkish, others again a sort of liver colour, and this last tint runs sometimes in blotches in the whiter stone, producing rather a singular effect.

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[*] "A Grain of Sand:" "Science for All," Vol. IV., p. 120.

[†] "The Gravel of the Garden Path:" "Science for All," Vol. II., p. 336. "A Piece of Puddingstone:" "Science for All," Vol. III., p. 341.

[‡] "On the Triassic and Permian Rocks of the Midland Counties."

[§] The Trias extends southwards from Central England to Devonshire, and there contains deposits separated from, but probably equivalent to the Bunter.

We proceed, then, on our search for the parent rock of these last. The more granular quartzite we may perhaps identify with a Silurian quartzite, which is still exposed to view in the ridgy hills to the west of Birmingham, called Bromsgrove Lickey; but the second and commoner one cannot be matched anywhere in England or in Wales. In the former there is, indeed, a quartzite beneath the Coal Measures at Hartshill, in Warwickshire, but that is not an exact match, and was almost certainly far beneath the ground when the Bunter pebble beds were formed. There are some quartzites in Wales, but either they do not match, or occur in quite insufficient quantities or in impossible localities. The mode in which the sediment in these Triassic beds is deposited leads us to suspect that its materials were derived from the north rather than from any other point of the compass, so we betake ourselves thither. Let us suppose that we have halted on the shores of Arran, on the west coast of Scotland. In the middle of the island rises the noble group of heather-clad mountains, the highest summit of which bears the name of Goat-fell. On their flanks are schists of unknown age, and the lower land is a mass of sandstone, assigned by geologists to the base of the Carboniferous series. It is riven by dykes of igneous rock, basalt, felstone, and pitchstone, but, except for this, we might readily imagine that we were standing upon some of the Bunter beds of Staffordshire. There are masses of red quartz sandstone, indistinguishable from that of Staffordshire, and beds of pebbles, in which we find an abundance of the same varieties of the harder quartzite that we have noticed in the south. Here, indeed, they are a little more angular in form, and with them there is a considerable admixture of schists, greywacké, and in other rocks which abound in the Scottish Highlands; the latter group are, indeed, more rare to the south, but this is no wonder, for they are much more perishable than the quartzite. Similar pebble beds occur in various other parts of the southern half of Scotland: in Bute, near Loch Lomond, Lesmahago, and other places recorded by Professor Hull. "No one," to quote his words, "can compare these pebbles with those from the Bunter conglomerate of England without being struck by their identity in mineral composition; and the comparison I have been able to make thus far confirms me in the impression I have for several years entertained, that, to some extent at least, the New Red Sandstone of England is daughter to the Old Red Sandstone of Scotland."

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* Quartzite is the name given to a metamorphosed (that is, altered) quartz sandstone.

But now, though we have tracked the Bunter pebbles back to parent rocks of earlier date in the north, they are pebbles still, and we have not yet discovered the source whence they were derived. To do this we must extend our researches yet farther north. In certain of the western islands—as, for example, Jura, and in the heart of the Highlands on the mainland—great beds of quartzite occur. We may select for description as a typical locality the picturesque shores of Loch Maree. There the basement rock is a group of highly crystalline hornblendic gneisses and schists, which is certainly among the most ancient in Britain, and is provisionally designated the Hebridean series. This is overlain by a massive reddish or chocolate-coloured hardened grit, called the Torridon Sandstone. Its geologic age is uncertain, but the included fragments show that an immense interval separates it from the underlying series, for this had been converted into a gneiss before any of the Torridon Sandstone was deposited. Above the latter comes a white or pale-coloured quartzite. As the Torridon Sandstone is well displayed in the massive crags of Ben Slioch, opposite to the well-known Loch Maree Hotel, so is the quartzite conspicuous in the snow-white peak of Ben Eay and on the western slopes of Glen Laggan. On examining this rock, we find the same compact half-melted aspect (the grains looking like those in a cold sago pudding) which characterises the Bunter pebbles. We see also no trace of fossils other than worm-burrows, which in one locality are abundant, and some rather similar markings, which may be these, or the impressions of seaweeds, or even some inorganic structure. In this district we find the usual colour of the quartzite white or pale grey, but the pebbles built into walls show us that other varieties do exist, and the liver-coloured quartzite, though absent here, may be seen abundantly in Jura.* There is, therefore, good reason to believe that we have at last tracked the pebbles to their birth-place. Our evidence, however, is not yet complete. If we carefully re-examine the heap of miscellaneous pebbles which we threw aside formerly, we shall probably find among them one or two which, though much decomposed, and looking at first sight rather like granite, present a very close resemblance to the Torridon Sandstone. They are not, indeed, in a condition very well fitted for microscopic examination, but on comparing slices from them with those from Loch Maree, we are justified in believing them to be the same rock, for the felspars, though decomposed, retain certain peculiarities of structure which are conspicuous in those of the latter rock. Again, on applying the microscope to the quartzite pebbles of Staffordshire and the quartzite rocks from Loch Maree, we observe that their general structure is the same, that their quartz grains correspond in certain minute peculiarities, and, what is a stronger argument, the few grains of felspar in each agree in exhibiting the peculiar structures (it would take too long to describe them in detail) which we note in those occurring in the underlying Torridon rock; and these exist also in the Hebridean group, whence the materials of both rocks have been derived.

What may be the geologic age of these Highland quartzites is no longer uncertain. At no time, however, were they considered to be more modern than Lower Silurian, and recent investigations have made it clear that they have been rightly assigned to this period. They are undoubtedly much older than the Old Red Sandstone and earlier Carboniferous periods, during which there seems little doubt the rocks of the Scottish Highlands underwent great denudation.

The chain of evidence, then, seems as complete as could be expected. We trace the pebbles first from the North-western Highlands, amid a crowd of miscellaneous rocks, to a halting-place in conglomerates of Old Red Sandstone and Lower Carboniferous age. Here they probably lay undisturbed during a long series of years, while in the marshy lowland tracts our present stores of fuel were being slowly accumulated: and then in the period which succeeded the Carboniferous beds were once more brought within the influence of disturbing forces. Torn from their resting-places, they were hurried southward by the strong currents of rivers, which hastened on to empty themselves into lake or sea, surviving most of their less durable companions, which in the long journey were ground to powder in the streams. To move these pebbles, on the average, would require a current flowing from two-and-a-half to three miles an hour a velocity quite equal to that of one of the great European rivers in the upper part of their course. Some, indeed, of these pebbles have not been permitted to rest even after their long southern migration, but may be recognised occasionally in the conglomerates of the Neocomian deposits in Bedfordshire, deposits which we have seen lie between the oolite and the chalk, and, as might be expected, in the miscellaneous collection of the Boulder Clay in which so many of the British rocks are represented.

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* For this fact I am indebted to the kindness of his the Duke of Argyll.

ANCIENT HORN-SHELLS.

By Charles Callaway, M.A., D.Sc., F.G.S.

In museums and similar institutions most of our readers have doubtless seen a circular stone, curiously resembling a serpent coiled upon itself, like the mainspring of a watch. In many parts of England these stones are very common, and the country people devoutly believe they are serpents which, for their own sins or the crime of their great ancestor in Eden, have been smitten into stone by the power of some indignant saint. St. Hilda, for example, is the virtuous lady whose "divine wrath" inflicted this doom on the snakes which are supposed to have once swarmed in the vicinity of Whitby. This theory, however, fails to answer such queries as these :—How did the serpents get into the solid rock in which they are now entombed? How is it that they are all destitute of heads? How is it that they all coiled themselves up into the same circular shape?

The ancients had another explanation of the origin of these fossils. They called them the horn of Ammon (*Cornu Ammonis*), from the name under which Jupiter was worshipped in Libya. The deity was represented under the form of a ram, and the curved fossil shells were his horns. It is to be presumed that the ancients believed that the god had been in the habit of shedding his horns, and dropping them all about the country. From this ancient name, the serpent-stones of our peasantry are called Ammonites. It is, perhaps, unnecessary to explain to our readers that Ammonites are neither serpents nor goats' horns, but sea shells which have been preserved in the earth's crust by the ordinary operations of Nature.*

The Ammonites and their allies belonged to the class of the Mollusca which goes by the name of Cephalopoda† (Gr. *kephalē*, a head, and *pous*, *podos*, a foot), because the mouth is surrounded by a ring of arm-like tentacles, supposed by the old naturalists to represent feet. The Cephalopods are separated into two divisions: those which possess a naked body with an internal shell, such as the cuttlefish and squid; and those which reside in an external shell, as the nautilus. The horn-shells belong to the latter. They are all extinct except the genus *Nautilus*, but as the solid parts, which are preserved in the rocks, are precisely on the type of that shell, we are reasonably certain that the soft parts also approximately corresponded. In describing the structure and habits of a nautilus, we are therefore placing before our readers a tolerably correct picture of one of the antique horn-shells and its inhabitant.

The soft parts of the pearly nautilus (*Nautilus pompilius*, Fig. 1) will first be described. The animal is enclosed in a fleshy mantle (*a*), which is thick in front, and forms a collar surrounding the head and its appendages; *b* is its dorsal

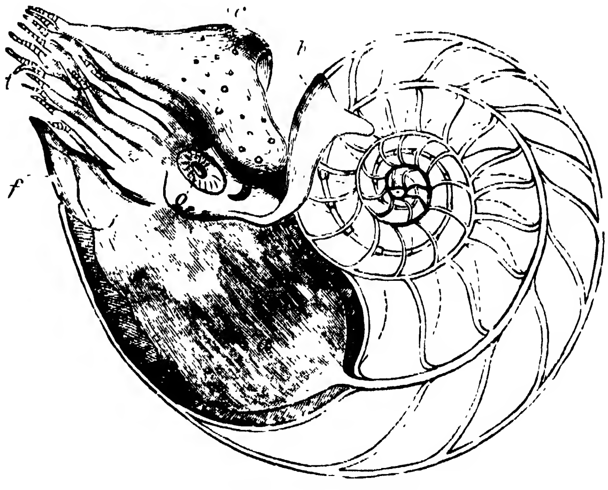

Fig. 1.—Pearly Nautilus. (*After Nicholson.*)

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* "Science for All," Vol. I., p. 132.

† "Science for All," Vol. III., p. 368.

fold. The hood (*c*) closes the opening of the shell when the nautilus withdraws itself. Muscular arms or tentacles (*t*) rise from the side of the head. They can be retracted within sheaths. Some of them are probably organs of touch. The mouth is situated in the centre of the head, and is surrounded by a circular fleshy lip. It opens below into a cavity, which is furnished with two horny mandibles, something like the beak of a parrot. The lingual ribbon, or tongue, is armed with recurved teeth behind, but is fleshy in front. The funnel (*f*) is formed by the folding of a thick muscular lobe. It is connected with respiration, and is also the organ by which locomotion is effected. Through the funnel successive jets of water are emitted, and the reaction propels the nautilus through the water.

The brain is large, and is protected in a gristly skull. There are the organs of five senses, as in man. The eyes (*o*) are prominent, and are placed on the sides of the head. External ears are also present on a small scale.

Digestion is carried on by a complex system of organs. The mouth opens into a gullet communicating with a large crop, on each side of which is a well-developed liver. The crop conducts to a gizzard, and the intestine ends at the base of the funnel.

The heart is divided into several chambers, and the organs of respiration are in the form of four pyramidal gills.*

The structure of the shell is very curious. It is divided into a series of chambers by partitions or *septa*, connected by a tube or *siphuncle*. The outside chamber, which is very large, is filled by the animal, and the others were previously occupied in succession. The siphuncle is a membranous tube with a thin pearly coating. It opens into the cavity containing the heart, and is probably filled with fluid from that opening. Its purpose is to maintain the vitality of the chambers. The air-chambers render the shell buoyant. The edges of the septa, where they appear on the shell, are called the *sutures*.

Little is known of the habits of the nautilus, but it seems probable that it feeds on shell-fish and crustacea, as its mandibles are adapted for crushing shells, and Professor Owen found the fragments of a small crab in the crop of the specimen he dissected. Owen quotes from an old writer, Rumphius, a Dutch naturalist, an account of the nautilus described amongst the rarities of Amboyna, in 1705. "When the nautilus floats on the water, he puts out his head and all his tentacles, and spreads them upon the water, with the poop of the shell above water; but at the bottom he creeps in the reverse position, with his boat above him, and with his head and tentacles upon the ground, making a tolerably quick progress. He keeps himself chiefly upon the ground, creeping also sometimes into the nets of the fishermen; but after a storm, as the weather becomes calm, they are seen in troops floating upon the water, being driven up by the agitation of the waves. This sailing, however, is not of long continuance; for, having taken in all their tentacles, they upset their boat, and so return to the bottom."

Fig. 2 is an ideal representation of the nautilus, fully expanded. The positions of the hood (*h*) and siphon (*s*) are shown.

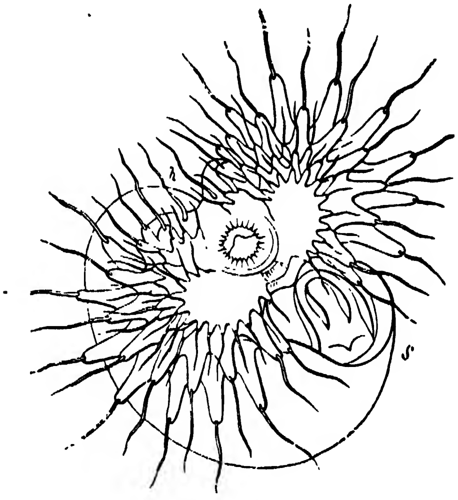

Fig. 2.—Nautilus expanded. (*After*

At the present day, the horn-shells are represented only by a few species of nautilus, the rare descendants of numerous and powerful families. The words of Tennyson—

> "A thousand types are gone,"

are more than realised. Several thousand extinct species have been already described; and there is no doubt that thousands more lie buried in their rocky sepulchres in the earth's crust. Examining their ancient records, the strata in which their fossil remains are preserved, we can present a continuous history of this singular race.

The horn-shells are first found in rocks of the Cambrian epoch; but they are few in number. In the Silurian period they attain a magnificent development in both numbers and variety.

The earliest form yet known is the Orthoceras

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* The two-gilled Cephalopods are described in Vol. III., p. 367.

(straight-horn). It is extremely like the shell of the nautilus, except that it is perfectly straight. It is shown in Fig. 3, in which the lower figure displays in section the form and position of the siphuncle.

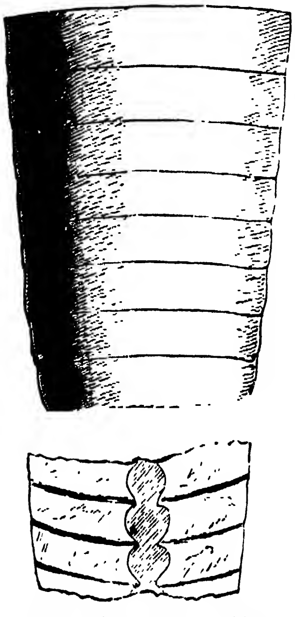

Fig. 3.—Orthoceras. (*After Nicholson.*)

Some of the specimens of Orthoceras are the largest of any known shell, fossil or recent. They have been known to attain the length of six feet, with a diameter of one foot. Such creatures must have been the monarchs of those ancient seas in which no fish, reptile, or other vertebrated animal, had yet come into being. With a huge circle of tentacles surmounting a pillar-like shell, they must have been the terror of the animated world. In some of the Orthoceras-like types, the animal could not, as in the pearly Nautilus, withdraw itself completely into its shell. In others the shell appears to have been less calcified, while the siphuncle is enormously developed. Some of these have been found in North America with siphuncles, like a row of gigantic beads, six feet long, standing out in bold relief from the face of the limestone cliffs. Their great durability is due to a subsequent change, called silicification, the calcareous substance being converted into flint. On the other hand, the septa are rarely preserved, and are only indicated in a few cases by faintly coloured lines.

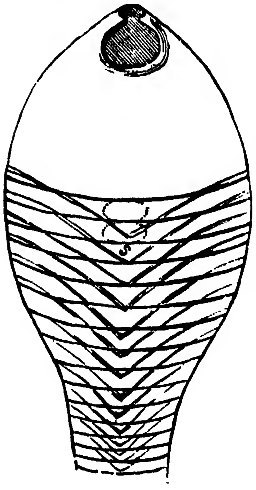

Fig. 4. Gomphoceras.

In one singular type, *Gomphoceras* (club-horn), the shell (Fig. 4) expands into the shape of a pear, and the aperture is contracted to an opening like a key-hole. The siphuncle (*s*) is bead-like.

Some of the Silurian horn-shells are slightly curved, others are more strongly bent, so as to form a coil, but with the coils not touching (*Gyroceras*, circle-horn); and in the latter part of the epoch, forms came into being in which the convolutions touched, and the nautilus commenced an existence which, with slight variations, has continued to the present day.

The horn-shells of the Devonian epoch make an approach towards the more modern Ammonite. The most characteristic type is *Clymenia* (Fig. 5), which is disc-shaped, has the siphuncle internal, and the septa simple, or, as in the figure, slightly lobed. In Germany, some of the Upper Devonian limestones are so full of these horn-shells as to have acquired the name of the "Clymenien Kalk."

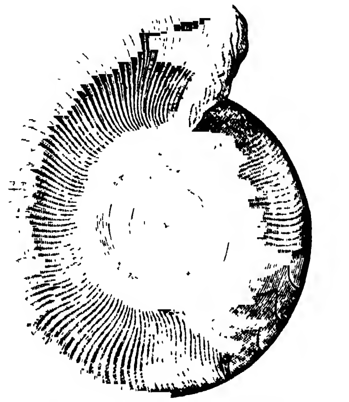

Fig. 5.—Clymenia. A, Side View ; B, Profile.

In the Carboniferous period a form abounds which is yet nearer to the Ammonite. This is the Goniatite (*gonia*, angles), which, like the Ammonite, is discoid, and has the siphuncle dorsal, but the sutures are angular, and are not lobed in so complex a manner as in the newer type (Fig. 6). The left-hand figure (A) is a side view, and the other (B) shows the fossil edgeways. Near the upper margin is the small dorsal siphuncle.

The Cephalopoda are very poorly represented in the Permian strata of Britain, and the few known forms belong to the genus Nautilus.

In the Triassic epoch, many of the older types, such as Orthoceras, are seen for the last time. One form is very characteristic of the period, and it is interesting as the herald of the great Ammonite family. It is the Ceratite (Fig. 7), which holds a position intermediate between the older Goniatite and the younger Ammonite. The lobes of the sutures are simply rounded, while the intermediate lines, the saddles, are toothed or crenulated. No horn-shells of this epoch are found in Britain, since the British area at that time was occupied by inland lakes; but in the Austrian Alps abundant remains are found, and these are of unique importance and interest. Associated with the

Ceratite are forms which, in other districts, appear to have died out, together with types which elsewhere, so far as our present knowledge goes, had not yet come into existence. Thus we have the antique Orthoceras, the earliest and simplest Cephalopod, in the same deposits with the Ammonite. And these Ammonites are not of an elementary or rude type; they are in the highest degree elaborate in structure and ornate in appearance. They exceed all Ammonites in the number and complexity of their lobes. The sutures, which hitherto have been plain, lobed, or angular, are foliated in the most curious manner, so that each lobe resembles a tree. Fig. 8 shows this peculiarity. It represents a single suture of one side; *v* is the dorsal saddle at the edge of the shell.

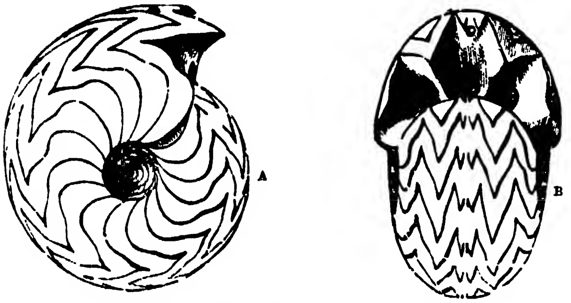

Fig. 6.—Goniatites. A, Side View; B, Profile. (*After Sowerby.*)

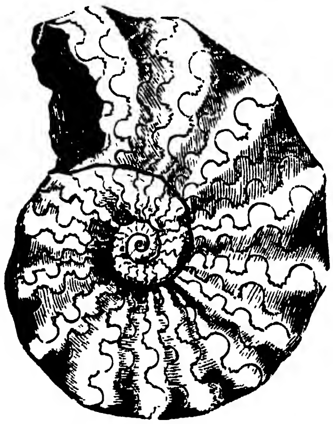

Fig. 7.—Ceratite.

Coming next to the Jurassic period, we find the horn-shells of the more ornate type, the Ammonite, amongst the predominating forms of life. The limestones and clays of our British deposits teem with their petrified shells. Sometimes the strata have been favourable to their preservation, so that, on disentombing the fossil, the Ammonite gleams forth from its rocky setting with the same pearly lustre as it displayed in life amidst the sunny waves of the Jurassic Sea. The compact clay in which the dead Ammonite was buried has kept out the water which produces so much change in the earth's crust. In other cases, the calcareous matter of the shell has been replaced by silica or flint. Sometimes the substance which has taken the place of the tissue of the shell is iron pyrites, so that the Ammonite seems converted into brass. Lastly, the shell has entirely perished, and a mould of the interior or a cast of the external sculpture alone is left.

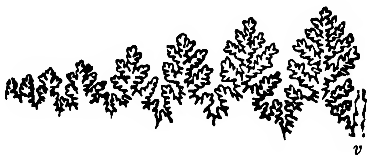

Fig. 8.—Triassic Ammonite. (*After Quenstedt.*)

Ammonites continue to be still abundant during the Cretaceous period, and, in addition to these, there come into existence a great variety of singular forms, some of which resemble, though their structure is more complex, types from the oldest formations. It seems as if, just before the Ammonite family passed into utter extinction, it effloresced into a more varied life, as though Nature, by one supreme effort, wrought her most elaborate work, and then sank exhausted. The Baculite (Fig. 9) is the modern representative of the Orthoceras. It is straight, but the sutures are foliated, and the siphuncle is external.

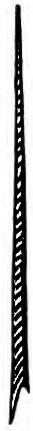

Fig. 9.—Baculite.

The genus *Toxoceras* (*toxon*, a bow, and *keras*, a horn) is simply bent like a bow. *Crioceras* (ram's horn) is disc-shaped, but, as in the ancient Gyroceras, the coils do not touch. *Hamites* (hook-shell) is bent like a hook. *Turrilites* (tower-shell) is an elongated spire, like a lofty tower. *Helicoceras* (spiral horn) is like the last, save that the coils do not touch. *Ancyloceras* (incurved horn) is an elegant shell. It resembles *Crioceras*, except that the last "volution" or whorl is produced at a tangent, and is then bent back like a crozier. *Scaphites* (boat-shell) differs from *Ancyloceras* in the fact that the coils are in contact, and the crozier-like extension is shorter.

The following diagram (after Nicholson) shows in a compact graphic form the chief modifications of the horn-shells (Fig. 10). The simplest types (*e*), as the Orthoceras or the Nautilus, have the siphuncle central and the sutures simple. Clymenia (*d*) differs chiefly in an internal siphuncle. The Goniatite (*c*), the first of the Ammonite family, possesses angulated sutures and a dorsal siphuncle. Ceratites and Ammonites have the siphuncle dorsal, but the sutures of the former are lobed and denticulated, while those of the later type are foliated. On the whole, there is progression from the simpler to the more complex forms, as we advance from the older to the younger epochs. But this is not the universal rule. The earliest types of the Ammonite, those which characterise the Triassic epoch, are much more elaborate and complex than some from the Jurassic and Cretaceous periods. Indeed, it seems as if the earliest and the latest Ammonites were the highest of their family.

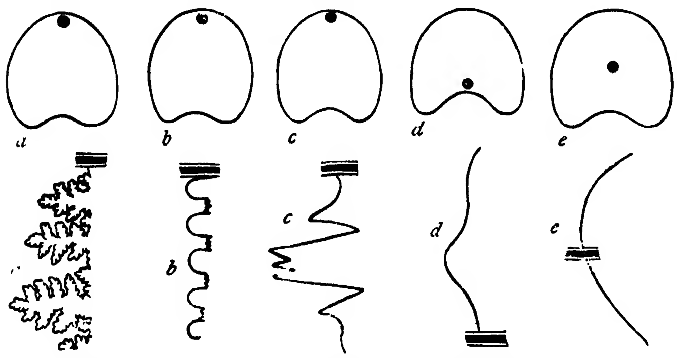

Fig. 10. -Diagram showing position of Siphuncle and form of Septa in various Horn-shells. The upper row indicates the position of Siphuncle, and the lower shows the edges of the Septa.
a, Ammonite; *b*, Ceratite; *c*, Goniatite; *d*, Clymenia; *e*, Nautilus.

But while the more complex horn-shells were being modified into varied forms, while family after family was coming into being, flourishing during long epochs and then sinking into extinction, the more simple and unadorned Nautilus has maintained "the even tenor of its way" from old Silurian times down to the Victorian age. It is associated with the primæval Orthoceras as well as with the more modern Ammonite and Ancyloceras. In every epoch it appears in moderate numbers, neither conspicuously abundant nor conspicuously scarce. It has always preserved its elegant shape, but has never taken the form of gorgeous beauty or wild eccentricity. It has usually kept its shell smooth, as at the present day, but in Jurassic times the surface was sometimes grooved, and in Cretaceous ages it was marked with distinct ribs. In brief, it is a good example of one of those permanent types of animals which live from age to age almost unchanged. At the close of the Cretaceous epoch all the Ammonites, with their numerous and varied allies, died out; and during the long succession of ages which compose the Tertiary era, the pearly nautilus of tropical seas remained the only representative of the ancient and once abundant race of horn-shells.

LOCUSTS AND GRASSHOPPERS.

By F. Buchanan White, M.D., F.L.S.

THERE is an ancient Arabian legend which expresses pithily and forcibly the estimation in which "the locust" is held by the unfortunate people subject to its visitations. "We are the army of the great God," said a locust, addressing Mohammed; "we produce ninety-nine eggs; if the hundred were completed, we should consume the whole earth, and all that is in it." To those who fortunately live in climes to which the locust rarely penetrates, this may seem Eastern exaggeration, and it is no doubt figurative; but to those who have seen "the land as the Garden of Eden before them, and behind them a desolate wilderness," it will scarcely appear too strong (Fig. 3). Consequently, from a very early period in the world's history the locust has attracted to itself more attention than perhaps any other insect, and not the least in the present day, when all the skill of science has been brought to bear against the dreaded ravager.

In reality, there is no single insect which ought to be termed, more than some others, *the* locust. Unfortunately, there are several which have earned for themselves the hatred and dread of mankind by the fearful devastation that they have committed, and still continue to commit; but all agree in this, that they are near relatives of the grasshoppers, whose merry chirpings make resonant the summer meadows. If, therefore, we capture a common grasshopper, and study his structure, we will have learnt all the essential details of the anatomy of the terrible locust (Fig. 1).

Though resembling in many respects the cockroach, already described,* and belonging, like it (as we shall presently see), to the same order of insects, the general appearance of the grasshopper is very different. Its body, instead of being flattened, is more or less compressed laterally, and consequently the wing-cases and wings, when not in use, present an almost perpendicular instead of a horizontal surface. Another striking point of difference is in the hind legs, which, being fitted for jumping, are much larger and stouter than the anterior two pairs.

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* "Science for All," Vol. III., p. 325.

The head is usually large, and often somewhat globose in shape; the face, or part seen from a front view, being either perpendicular, or sloping backwards from above downwards. On each side are the rather large compound eyes usually found in insects. Without entering into lengthy details, the structure of these eyes may be briefly described. As mentioned on a previous occasion, the horny skin, or external skeleton of insects, is composed of a material termed chitine. At the place where the eye is situated this chitinous cuticle is somewhat thickened, and becomes transparent, to form the cornea, which is furthermore divided into a number of six-sided facets. Between the inner surface of each of these facets and the end of the optic nerve is a transparent, elongated body enveloped in a sheath, which is supplied with pigment. These elongated bodies consist of two parts, of which the inner one, or that which is in contact with the optic nerve, is called the *prismatic rod*, while the outer one is termed the *crystalline cone*. The broad end of the latter touches the inner surface of the cornea, and its narrow end is continuous with the prismatic rod. In addition to these *compound eyes*, many grasshoppers are provided with three *simple eyes*, situated more or less in front of the head, two being above, between the compound eyes, and the third a little lower down, and in the middle. These simple eyes (or *ocelli*, as they are technically called) have been likened to the eyes of the higher (or vertebrate) animals, and have been supposed to be made, as in them, of various parts, to which the names of sclerotic, cornea, lens, vitreous humour, and choroid coat have been given; but there is reason to suppose that some of these do not exactly correspond to the parts so called in the vertebrate eye.

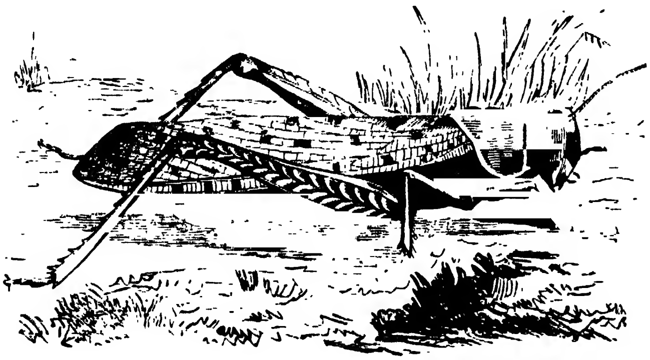

Fig. 1.—Locust (*Acridium migratorium*).

In front of the head, between the compound eyes, are situated the *antennæ*, not longer than half the length of the body, and composed of a number of joints. In shape they are frequently thread-like, but in some kinds of grasshoppers they are sword- or club-shaped (Fig. 2).

At the lowest part of the head is situated the mouth, which, like that of the cockroach, is formed for biting, and is constructed after the same plan, and so need not be described in detail. The upper lip, or labrum, is sometimes notched at the front margin; the mandibles, or upper jaws, are very strong, and provided with many teeth, and the labium, or lower lip, has only two lobes instead of four.

The pronotum, or upper surface of the first ring of the chest or thorax, is somewhat variable in shape in the various species. In some it is provided with a central longitudinal ridge or crest, or with less conspicuous lateral ones, and in others it is much prolonged backwards in a more or less broad spine-like process, overlying the abdomen, and sometimes as long as it. The other two rings of the thorax are not visible from above, except when the wing-cases and wings are expanded, and even then are in some cases hidden by the prolonged pronotum. The under-side of the thorax does not require particular description, beyond mentioning the fact that occasionally it is armed with a spine situated between the front legs. To the second and third wings of the thorax are attached (as usual) the organs of flight. These consist of the anterior wings, which, as serving mostly as covers to the wings, are called wing-cases, or tegmina, and of the hind wings, or wings proper. The wing-cases are somewhat leathery in texture, more or less long, and narrow in shape, and strengthened by numerous thicker veins. Occasionally they are very short, especially in those species which have a prolonged pronotum, which serves to protect the wings. The true wings vary in size, but are often large. In texture they are membranous, and are also provided with longitudinal veins (often connected by finer transverse ones), by which they are expanded. When not in use they are folded longitudinally, and stowed away under the wing-cases. The latter are usually dull in colour, frequently brown or grey, and banded and spotted with darker or lighter shades. The wings, on the other hand, are either clear and colourless, or tinged with some bright hue, as red. blue, or yellow, and occasionally banded with black. Sometimes both wing-cases and wings are wanting, or only partly developed.

The anterior two pairs of legs are moderate in size, the last joint, or tarsus, being formed of three smaller pieces, the first of which has on the under side three spongy or leathery cushions, and the second one. These two pairs of legs are fitted for running, the well-known jump of the grasshopper being performed by means of the third pair, which consequently are adapted thereto, and demand more attention. These hind legs are not only much longer than the two anterior pairs, but have the femora, or thighs, much stouter and thicker, as it is in them that the powerful muscles, by which the grasshopper can take his enormous—in comparison with the size of the insect — leaps, are contained. The hinder edge of the thigh is channelled, so as to partly contain the tibia (or next joint of the leg) when at rest. The upper side of the tibia, especially towards the tip, is furnished with numerous strong spines, which, by offering resistance to the surface from which the insect jumps, help it considerably in making its leap. The tarsus of the hind leg is constructed as in the front legs.

In addition to serving as organs of progression, the legs and wings (or rather portions of them) of the grasshopper are used as vocal organs. It is by means of his hind legs and his wing-cases that the well-known song of the grasshopper is produced, a fact which everyone may observe for themselves by watching the insect when at work. The sound is produced thus:—The insect stands on his four front legs, and lifting, either together or alternately, his hind legs, rubs the rough inner edge of the thigh against the wing-case. The latter is provided (as mentioned above) with thickened veins, and according to the degree in which these veins are thickened and elevated above the surface of the wing-case so is the noise which results. Some grasshoppers do not seem to be able to make any sound, and others, though they go through the action, produce no sound audible to human ears, though it seems probable that it is heard by their companions. By catching a grasshopper, and rubbing its hind legs in the manner mentioned, anyone can see for himself that the sound is produced in the manner described. It is only the males that make an audible sound, and the object seems to be chiefly to attract and captivate the females. In other words, it is a love-song.

In most insects, if a special organ of hearing exists, it is difficult of detection; but in the grasshoppers, in whom the sense of hearing seems to be very acute, there is a well-developed ear, or its equivalent. This is situated on either side of the first segment of the abdomen, near the articulation of the hind legs to the third ring of the thorax, and consists of a round, crescent-shaped, or linear opening, inside which is stretched an oval membrane surrounded by a raised rim (Fig. 2, A, *a*). On the inside of the membrane are two horny (chitinous) projections (Fig. 2, B, *b*, *c*), the larger of which ends in a delicate bladder (filled with clear fluid), which sends off a small arm to the smaller horny projection. A nerve (derived from the "metathoracic ganglion") goes to the centre of the membrane, and there dilates into a ganglion (depot of nerve-force), the side of which nearest to the membrane is covered with numerous glassy rods in contact with the membrane. A branch of the nerve goes also along the horny projection to the delicate bladder at its end, where it forms a ganglion, from which several nerve-fibres spread over the bladder. If a grasshopper is watched when chirping it will be seen that when his "song" is ended he lowers one, or both legs, and keeps his wing-cases a little raised, in order, apparently, to hear if any other male will answer his challenge. On the other hand, if he is chirping to please the female, he places himself in such a position that the sound will fall on her ear, which she may be seen to be keeping exposed for the purpose.

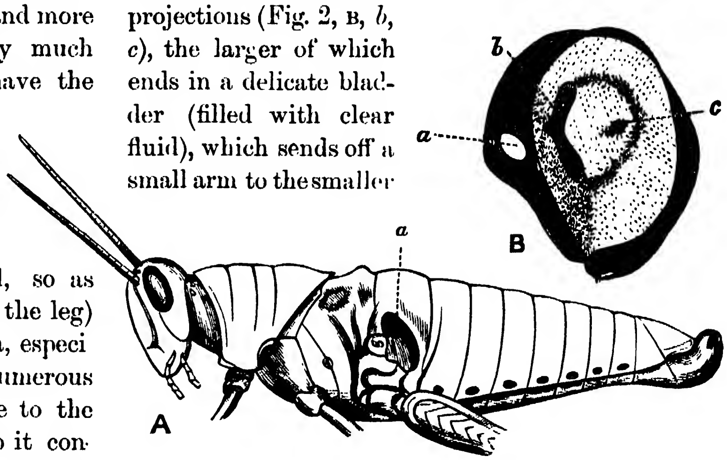

Fig. 2.—Auditory Apparatus of Grasshopper.

A, Figure showing position of Apparatus; *a*. Tympanum. B. External surface of Apparatus (left outer ear); *a*, opening of the stigma in the raised rim of the Tympanum; *b*, the larger horny projection seen through the semi-transparent Tympanum; *c*, the smaller horny projection.

The abdomen is rather compressed and keeled above and almost convex below, tapering from the base to the end in the female, but somewhat inflated at the end in the male, in which sex also it is more slender. In each sex there are nine distinct segments or rings, in addition to the organs connected with reproduction, which are conspicuous at the end of the abdomen. Of the latter, the most interesting is the ovipositor, or apparatus by which the female makes holes in the ground for the deposition of the eggs. The method of using this apparatus, which consists of four hook-like valves, the two upper curved upwards, and the two lower curved downwards, will be described presently.

The internal structure of grasshoppers and locusts, though formed on the same plan as the cockroach's, differs in some particulars.

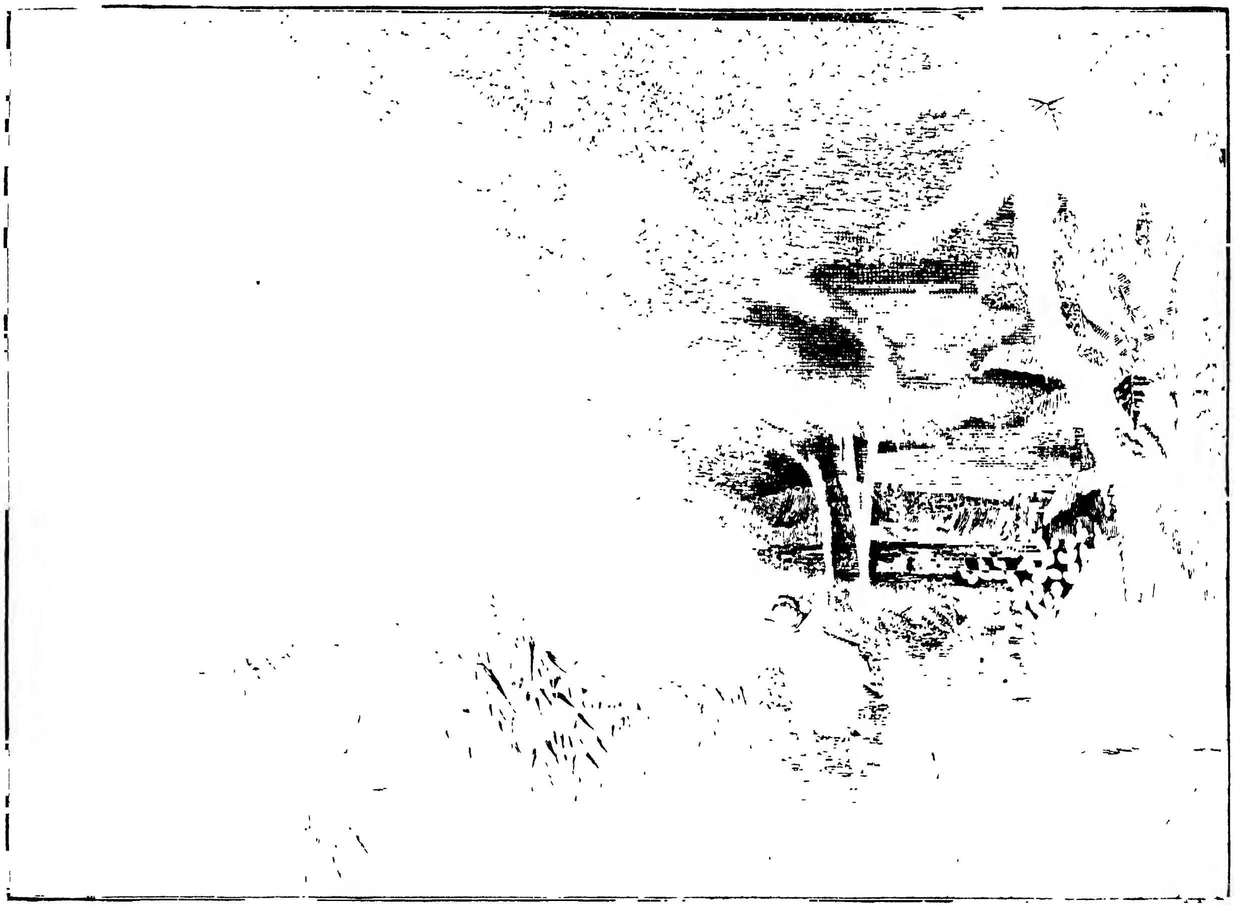

Fig. 3.—A Cloud of Locusts in Algeria.

The alimentary canal is the same length as the body, and is extended in a straight line, and not convoluted, as in the cockroach. The tongue is larger than in any other of the families of the Orthoptera. The gullet is short, and soon widens out into the crop, at whose base are situated six membranous, muscular, bag-like appendages, called the *bursæ ventriculares.* There is no gizzard in this family, the crop opening directly into the ventriculus, at whose junction with the crop is another series of six bag-like appendages—the *bursæ accessoriæ.* Following the ventriculus is the intestine proper, consisting of the slender intestine and the rectum. At the junction of the ventriculus and the intestine are inserted a large number of slender tubes—the Malpighian glands. In texture and substance, the various parts of the alimentary canal are thus composed. The crop is strong and muscular, and is, on its internal surface, provided with many somewhat cartilaginous striations, transverse near the gullet, but longitudinal in other parts, interrupted, and hence rough. On the lower side there is, anteriorly, an oblong oval space without the cartilaginous striation, but surrounded by a hardened and thickened margin. At the junction of the crop and the ventriculus is a valve (the *valvula conoidea*), consisting of six thickened and somewhat hardened eminences, which, when the whole crop is contracted, come together, and close it at the base. Some authors have considered that this valve represents the gizzard. The ventriculus is soft, and is also capable of expansion. The slender intestine has externally six longitudinal muscular narrow bands, starting from its junction with the ventriculus, but not extending to the end.

Internally, these form fleshy elevations. The rectum has also six longitudinal muscular bands. Between the ventriculus and the slender intestine, and between the latter and the rectum, are kinds of valves by which they can be closed.

The salivary glands, which open into the gullet, are much smaller and more delicately branched than in the cockroach, and are not provided with salivary receptacles.

The breathing system has some peculiarities, inasmuch as, in addition to the usual elastic tubes, or tracheæ, there are membranous tubes widening into large air-bags, which greatly assist the flying powers of many of the species.

The blood circulatory system and the nervous system do not require special description, though the latter is, if anything, more developed than in the cockroaches, and there is (as mentioned above) a special nerve for the auditory apparatus.

In magnitude, grasshoppers vary considerably. Some species are not a quarter of an inch in length, while others are amongst the largest insects known, and measure nearly a foot across the expanded wings.

The animals commonly known as grasshoppers and locusts belong to the order (or division) of insects called Orthoptera, the points of distinction between which and other insects have been pointed out in a previous paper. The particular family to which they belong is the Acridiodea, the members of which may, by an uninstructed eye, be confounded with those of another family—the Locustina—whose component members are also sometimes called grasshoppers, though for the most part frequenting trees. Insects belonging to the Locustina may be distinguished from the Acridiodea by their thread-like antennæ, usually much longer than the body, by their tarsi having four joints instead of three, by not (usually) being provided with single eyes (*ocelli*), by the much longer and exserted ovipositor of the females, and by the different position of the sound-producing apparatus of the males, as well as in some other particulars into which we need not enter at present. The "great green grasshopper" (*Locusta viridissima*) is a good example of this family, and also of the unfortunate, but now unavoidable, use of the word "Locusta" as a scientific name for insects not belonging to the family of the true locusts. The Acridiodea may also, but not so readily, be confounded with another family of the Orthoptera—the Gryllodea, which include the house and field crickets; but these may be distinguished by their long and slender antennæ, and by their wing-covers being, partly at least, horizontal when at rest.

From the great ravages committed by them, locusts have, as it were, compelled the attention of man, and hence their mode of living and metamorphoses have been often and carefully studied. As the metamorphoses and habits of many of the species are not very dissimilar, we will select for description a species whose history has been carefully worked out of late years, in consequence of the havoc it has committed in some parts of North America. This is the Rocky Mountain locust (*Caloptenus spretus*), a species not much bigger than many of our common grasshoppers (Figs. 4, 5, 6).

When a female wishes to lay eggs, she selects, by preference, a bare, dry, sandy place, where the ground is firm, and not loose. Recently-ploughed land is avoided, and so is damp ground, but a field or pasture where the vegetation is sufficiently short is often chosen. Having selected the place, the grasshopper closes the hook-like valves already described as situated at the end of her abdomen, and forcing them into the ground by curving her body, she then, by alternately opening and closing them, and by a series of muscular efforts, drills a hole sufficiently large to hold nearly the whole of her abdomen (Fig. 4). During this operation she stands upon her first and second pair of legs, and hoists the longer third pair above her back. The hole then made is always more or less oblique, and generally a little curved, and narrower at the mouth, and is made in a few minutes, the time varying according to the hardness of the soil. When engaged in drilling the hole, the insect is so intent on her work that she may be closely approached if care is taken not to alarm her. Having completed the hole, she next proceeds to lay her eggs in it. First of all she fills the bottom of the

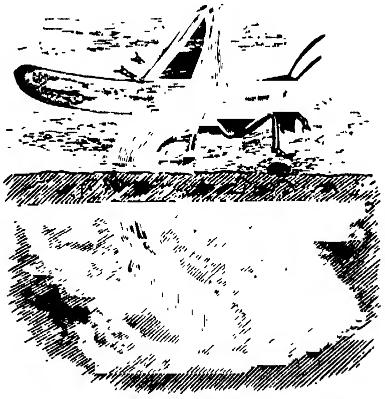

Fig. 4.—Female Locust depositing Eggs. (*After Bulletin of U.S. Entomological Commission.*)

hole with a frothy mucous or glutinous matter which is produced by a pair of special sponge-like organs at the end of the abdomen. Then the hook-like valves are brought close together, and between them an egg slips down from the oviduct, and is placed amongst the frothy matter. Again, by a series of convulsions, more of the frothy matter is produced, and then another egg is laid, and so on, till the whole number has been deposited, after which the narrow mouth of the hole is filled up with a compact mass of the frothy mucous matter. The use of this froth-like matter is to protect the eggs, especially from water, to which it is more or less impervious, and also to keep all the eggs in their places, as it forms a spongy or membranous packing through which the young insect can easily force its way.

The egg (Fig. 5) is somewhat oval-oblong in form, with a slight curvature, and rather narrower at one end. It has two coverings, the outer one thin, semi-opaque, and pale yellow in colour, rather fragile, and with the surface covered with minute six-sided pits ; the inner covering is thicker, tough, transparent, and smooth. The number of eggs varies from twenty to thirty-five, but is generally twenty-eight, and they are laid in four rows of seven each, very carefully arranged with the narrow end downwards (Fig. 6), and so placed that along the upper surface of the mass is a kind of irregular channel by which the first-hatched young ones can escape without disturbing the other eggs. This is very necessary, because it is generally the first-laid eggs that hatch first, and as they are at the bottom of the hole the arrangement of the mass would otherwise be necessarily disturbed. As the eggs when deposited are somewhat soft and plastic, the outer rows are made to curve over the inner rows to a certain extent.

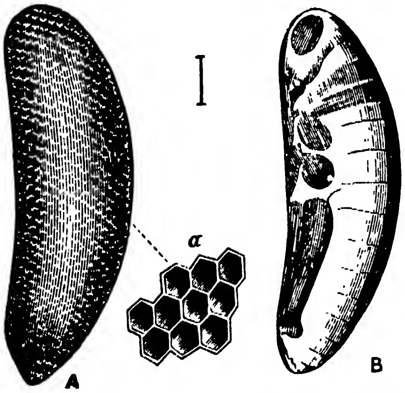

Fig. 5.—Egg of Locust. A, Outer Shell, showing sculpture ; a, Same, very highly magnified ; B, Inner Shell, just before hatching. (*After Bulletin of U.S. Entomological Commission.*)

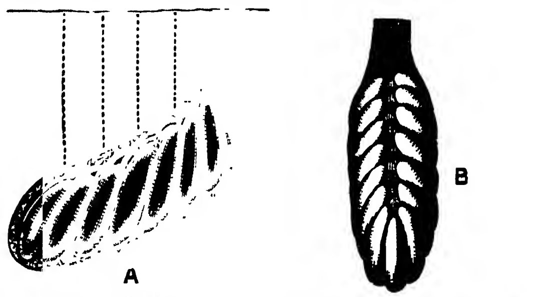

Fig. 6.—Egg Mass of Locust. A, From the side, within Burrow ; B, From above—enlarged. (*After Bulletin of U.S. Entomological Commission.*) The dotted lines show the direction often taken by the young insect to reach the surface of the earth.

When the young grasshopper is ready to come out of the egg, it has to find some means to break through the coverings, and, as already remarked, the inner covering is very tough, and not easily ruptured. When in the egg the back of the embryo is against the longer curve of the egg, the underside of the body with its various appendages being against the shorter curve (Fig. 5, B). The jaws and other parts of the mouth are bent down upon the chest, the sharp end of the jaws pressing against the wall of the egg. The legs are doubled up, the tibiæ of the hind legs fitting into the groove of the thighs, and the spines (which have been mentioned as arming the tibiæ) pressing against the egg-wall. The tarsi claws also are in a similar position. Now, when the young one is ready to come forth, there begins a series of undulating contractions and expansions of the joints of the body, which results in pressure on the shorter curve of the shell, and at the same time continued friction of the tips of the jaws, spines of the hind tibiæ, and claws of all the legs, till at last the skin splits, the split is extended by the swelling of the head, and the young grasshopper wriggles itself out of the egg-shell. It then makes its way to the surface of the earth, either by forcing a passage through the spongy matter, or else directly through the soil if that is not too compact. When pushing to the surface, the antennæ and two anterior pairs of legs are generally closely applied to the chest and the hind legs stretched out. A remarkable fact is that the young insect never attempts to go in any direction but upwards. The members of the United States Entomological Commission (from whose "Bulletin" much of the information relating to the egg-laying has been taken), placed eggs in earth in glass tubes, and found that the newly-hatched young always turned their heads and pushed towards the bottom whenever the tubes were turned mouth downwards.

As soon as it arrives at the surface, the young grasshopper, after resting for a short time, proceeds to cast its skin, or rather a thin pellicle which completely envelops it. It does not attempt to do this before reaching the surface, and if by any means the pellicle should get rubbed off during the insect's exertions to get out of the earth, it seems unable to make further efforts to push its way through. The use, therefore, of this embryonic skin seems to be to protect it from injury during the struggle. The pellicle is burst on the back of the head by a series of contracting and expanding motions, and then, gradually working it off, the animal issues, pale and colourless, but becomes dark grey in the course of half-an-hour or so.

The number of eggs laid by the Rocky Mountain locust is, as stated above, between twenty and thirty-five; but some other kinds lay a larger number. The true migratory locust (*Pachytylus migratorius*) lays from fifty to a hundred in each hole or nest, and as she usually deposits at least three times, the total number of eggs laid may be one hundred and sixty to one hundred and seventy. All species, so far as is known, form holes in the ground in which to deposit their eggs, and envelop them in the same kind of glutinous frothy matter as has been described above.

Like young cockroaches, the young grasshoppers and locusts resemble their parents in all respects, except in being very much smaller and in not being provided with wings and wing-cases. They moult or change their skins about four times, the rudiments of the wing-cases and wings appearing after the first moult, and becoming larger during each subsequent one, till at the fourth or last moult the insect reaches the mature or perfect state, is able to reproduce its kind, and, except in the few species which are unprovided with these organs, acquires full-sized wing-cases and wings. The moulting or changing of the skin is thus accomplished:—When the insect feels that the time has come, it fixes itself by the claws of the hind legs to some suitable object, such as a grass stalk, usually with the head downwards. Here it remains motionless for several hours, till the back of the thorax begins to visibly swell. Presently, the skin along the middle line of the head and thorax splits, and the soft white new skin of the insect protrudes from the opening. (If we were to take a specimen just about to moult, and to carefully cut open the skin, we would find that the whole animal was covered by the new skin lying ready formed below the old one.) Then by a series of wrigglings, the insect works itself out of its old skin, the end of the abdomen and the hind legs being the parts last extricated, and stands beside it, soft, pale-coloured, and powerless. Soon, however, the new skin begins to harden and acquire its proper colour, and the insect becomes strong, and commences to move and feed. Should it have been the last moult that has taken place, the wings and wing-cases will now have been acquired. These are at first crumpled and flabby, but soon straighten and expand, and are then folded away into their proper places, and perhaps in an hour afterwards are ready for use. The time taken for the moulting varies in different species, or at least according to different observers. In the migratory locust the moult is said to occupy sixteen minutes, and the expansion of the wings twenty or twenty-two minutes more. In most species it takes place during the hottest sunshine.

The eggs of most species are laid in late summer or autumn, and remain unhatched till the following spring, and the insects arrive at the perfect state in summer and die before winter. Very few kinds live over the winter, though a few do so.

These insects usually inhabit fields and meadows, or dry rocky or sandy uncultivated ground. A few live in damp fields, and some dwell amongst bushes and trees. They all jump well, and many are good fliers, though others seem but to take short flights, using their wings to assist their leaps. Some, if they fall into small pools or ditches of water, can swim sufficiently well to enable them to get to land again; a few exotic species seem to be semi-aquatic in their habits, remaining even for some time below the surface of the water. Almost all plants are eaten by these insects, but grasses seem their favourite food. They will, however, eat the leaves of trees, and even the bark and sometimes the wood, if other food fails—at which times also straw, thatch, and woollen clothes have been devoured. They are not altogether free from cannibalistic propensities, as numbers of the Rocky Mountain locusts are said to be eaten when in the helpless condition of moulting by their stronger brethren. The migratory locust is also guilty of a similar crime, and possibly all species are more or less given to it, at least under the pressure of starvation.

A few words must now be devoted to the particular habits of some of those species which have made the name of locust (or its equivalents in other languages) famous, or rather infamous, over a great part of the earth. It must not be thought that the word locust is given to one species only. It applies, as said already, equally to several kinds of grasshoppers which have made themselves notorious by the devastations caused by their almost indiscriminate voracity for vegetable substances. In the Old World, if there is one species (amongst several) which may be termed *par excellence* "the locust," it is *Pachytylus migratorius*. In North America, on the other hand, the locust is *Caloptenus spretus*, the Rocky Mountain locust.

If we trace the history of a band of the latter, we will be able to form some idea of how locusts commit such havoc amongst vegetation. After they are hatched, the young locusts begin to show their social or gregarious proclivities by congregating together in warm and sunny spots, feeding upon such plants as are most attractive to them. As they increase in size they require more food, and

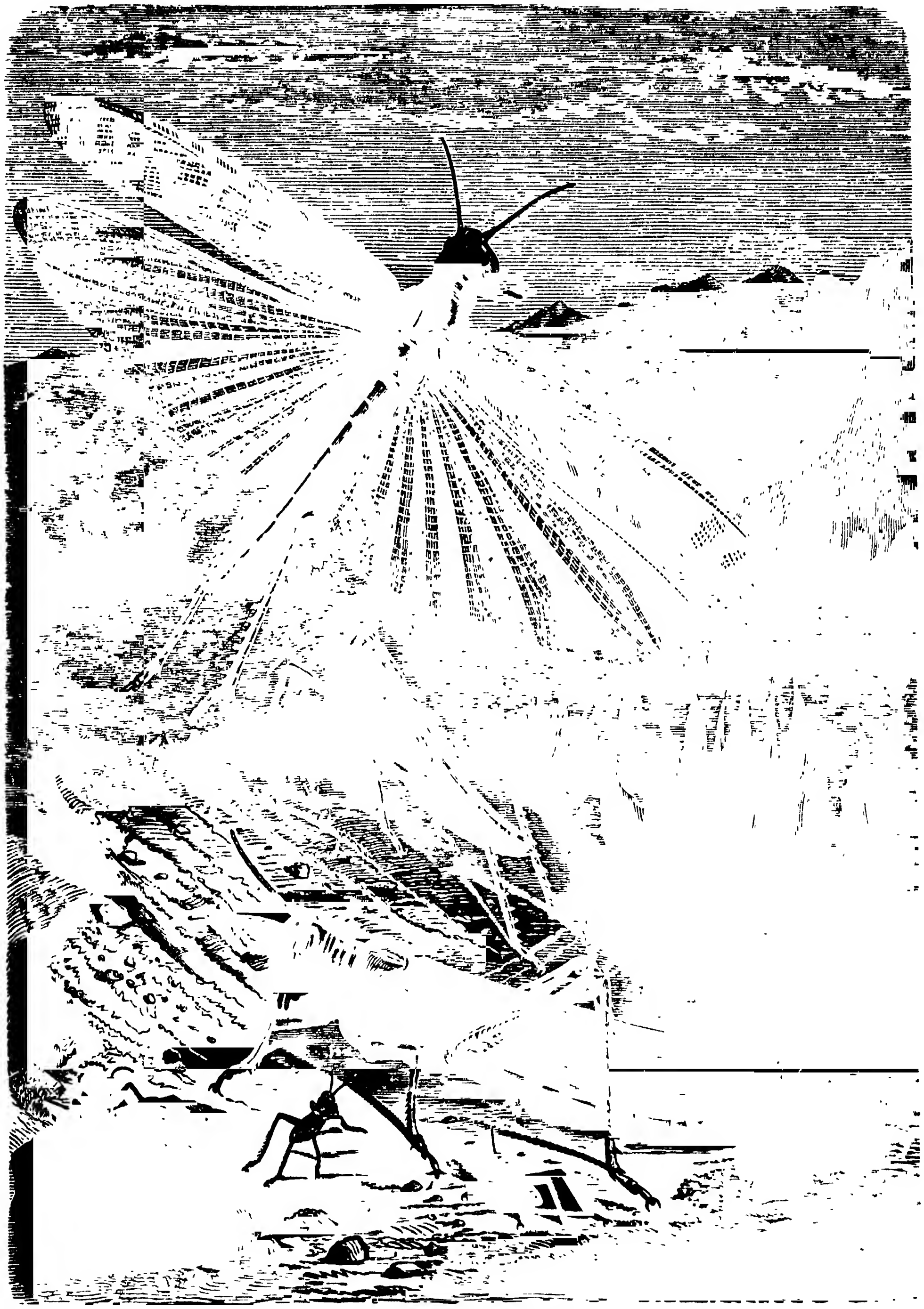

Fig. 7.—Metamorphoses of the Locust (*Acrydium peregrinum*).

by their great numbers soon clear the ground of vegetation. Till after the first moult (that is, the first true moult, not the casting of the pellicle that enveloped them when first hatched) they, however, do not commence to migrate. After that, having eaten up all the food in their vicinity, they are forced to set out on their travels in search of more food. They march, often in a swarm a mile wide, during the warmer hours of the day, clearing out everything eatable in their path. When they come to woods they first of all clear out the brushwood, and eat the dead leaves and bark. "A few succeed in climbing up into the rougher-barked trees, where they feed upon the foliage, and it is amusing to see with what avidity the famished individuals below scramble for any fallen leaf that the more fortunate mounted ones may chance to sever." They continue to increase in destructiveness till after the third moult, after which they begin to decrease in numbers, from starvation, disease, and the attack of enemies. Comparatively few attain the perfect or winged condition, and then return, so far as they are able, to the places where they were hatched, not many miles distant, and do comparatively little damage.

In many respects, the life of the Old World locusts, especially the migratory locust (*Pachytylus migratorius*) is similar to the one just sketched. Like the Rocky Mountain locust, the migratory locust does not commence to migrate till after the first moult, and not to any great extent till after the second. Their time of marching is generally the morning and evening, and they also devour (as they did in the summer of 1880 in Southern Russia) almost every green thing, leaving a wilderness behind them. When they attain the winged condition they do not cease from the work of destruction, and occasionally fly in immense swarms and to great distances. Multitudes of one kind of locust, *Acrydium peregrinum* (Fig. 7), perhaps the species mentioned in the tenth chapter of Exodus, were once seen during a storm in the Atlantic 1,200 miles from land, and great swarms of the same species interrupted the march of a French army in Algeria. (Fig. 3). As a rule, however, it is supposed that they do not wander far from the districts in which they were hatched.

In the northern half of Europe (including Britain) locusts of several kinds occasionally appear, but generally only in small numbers, and without doing any mischief. South, however, of a line drawn from Spain, through the south of France, Switzerland, Pomerania, South Russia, and South Siberia, to the north of China, they have again and again wrought dire havoc. A few of the more noted devastations may be mentioned. These devastations—where every plant is devoured—entail of course the starvation of the men and beasts whose food supply has been thus taken from them. But the mischief does not cease with that. Pestilence usually follows, and is produced or aggravated by the effluvia from the decaying bodies of the dead locusts, especially when, as has been frequently the case, the insects have been blown into the sea, and afterwards cast up on the shore by the waves. On one occasion (about the end of last century) so many perished in the sea on part of the African coast that a bank three or four feet high, and about fifty miles long, was formed on the shore by their dead bodies, and the stench of them was carried 150 miles by the wind. In another part of Africa, early in the Christian era, one plague of locusts is said to have caused the death of 800,000 persons; and in 591 nearly as bad a plague occurred in Italy. Again, in 1478, more than 30,000 persons perished in the Venetian territories from famine caused by locusts. Since that time there have been, unfortunately, too many records of locust-plagues, from which it would seem that the old stories are by no means exaggerated. In more than one account, and these comparatively recent, the swarms are described as so dense as to have actually eclipsed the sun, and this not for a few minutes, but for hours at a time, so that when the prophet Joel says that before them "the sun and moon shall be dark, and the stars withdraw their shining," he was speaking literally, and not metaphorically.

There have been, naturally, many attempts made either to prevent or to arrest the plagues of locusts, and in the United States of America the Government some years ago appointed an Entomological Commission to investigate and report on the best means of accomplishing these very desirable objects. As prevention is better than cure, it is evident that steps taken to destroy the eggs or newly-hatched insects will prove most efficacious, a plan which was long (and may still be) in use in the south of France. In other places, to destroy the half or full grown insects, trenches are dug in the ground, into which they are driven, and then destroyed by being covered with earth.

From a very remote antiquity locusts have formed an article of food, not only in Africa and Asia, but even in ancient times in Europe. Sometimes they are smoked or salted, at others they are fried or ground or powdered and mixed with flour to make bread. This is not done only in times of famine, but also when there is no scarcity of other food, as the locusts are considered rather a delicacy than otherwise. A few years ago Dr. Riley, Chief of the U.S. Entomological Commission, organised a banquet at St. Louis, where locusts in various forms were served up, and were pronounced excellent food. From time immemorial the Digger Indians, in the desert country west of the Rocky Mountains, have also used locusts as articles of food. *

Like several other families of the Orthoptera, grasshoppers have a considerable antiquity, since a fossil species has been found in the coal measures of Saarbrück.

A SUN-DIAL.

By William Lawson, F.R.G.S.,

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SUN-DIALS are now seldom met with, though we may still occasionally see one fixed to the south side of an old church, or standing as an ornament in a garden. But at one time they were much more common, and, indeed, before clocks and watches were invented were almost the only means of measuring time with any approach to accuracy. The instrument has been in use from the earliest times. The Hebrews were acquainted with it at least seven centuries before the Christian era. We all recollect the sign given by the prophet to King Hezekiah, that the shadow should go ten degrees backward on "the dial of Ahaz" (Isa. xxxviii. 8). The Greeks derived their knowledge of it from their Eastern neighbours, and by them it was introduced among the Romans. In our own country down as late as the seventeenth century no mathematical treatises were so common as those on dialling, and this branch of mathematical astronomy may still occasionally be met with in old text-books. The dial, of course, always laboured under the disadvantage of not being of any use in cloudy weather, or after sunset; and hence, in very early times, it was customary to calculate the hours of night from the position of some prominent star. Arago tells us that the Abbot of Cluny consulted the stars when he wished to know the time for midnight prayers; at other times a monk remained awake, and, in order to measure the lapse of time, repeated certain Psalms, having learnt by experiment how many he could say in an hour.

The principle on which the sun-dial is constructed may be easily explained. Owing to the earth's rotation, the sun appears to move round our globe in twenty-four hours. The circumference of the earth is, of course, a circle, and every circle is divided into 360 degrees. Hence the sun appears to pass over 360 degrees in twenty-four hours, or fifteen degrees in one hour.† When, at any place, the sun reaches the meridian—that is, its greatest altitude on any given day—it is said to be noon, and we call the hour twelve. Suppose, then, it is twelve o'clock at Greenwich, it will be evident, from what has been said, that at a place fifteen degrees to the west of Greenwich it will be eleven, while at a place fifteen degrees east it will be one o'clock. Let P, B, P′, D (Fig. 1), represent the earth as a hollow, transparent sphere, having an axis P, E, P′, on which it turns. P, P′, will be the poles of the axis, and the dotted line mid-way between them will represent the equator. Let the equator be divided into twenty-four equal parts, and through these divisions draw the meridians 1, 2, 3, &c. These meridians will, of course, be fifteen degrees apart. For the sake of clearness we put only twelve of these in the diagram. Let B be a point about 50° north of the equator, and therefore somewhere in the neighbourhood of London; and let us suppose the sphere cut through by the horizontal plane A, B, C, D. Now if the axis P, E, P′ be opaque, the sun in its apparent motion round the earth—caused, as we know, by the earth's rotation on its axis—will pass from one meridian to another at regular intervals of one hour, and cause the shadow of the axis to fall upon the horizontal plane. Thus if at one o'clock it falls upon the point B, an hour later the shadow will be on II.; two hours later, at III.; and so on. An hour before one, the shadow will be at XII.; two hours before, at XI.

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* Brown: "Peoples of the World," Vol. I., p. 142.

† "The Mechanism of the Heavens:" "Science for All," Vol. I., p. 90.

Now in a sun-dial the plane A, B, C, D, may be represented by a horizontal slab of slate, marble, or brass. A triangular piece of metal, similar to A, C, B (Fig. 2), called a gnomon, stands perpendicularly on the slab, the line A, B, being due north and south. The line A, C, called the style, points to the Pole star, and is therefore parallel with the earth's axis, and thus corresponds with P, E, P′. When the sun is on the meridian, the point where the shadow of the gnomon falls is marked XII. Earlier in the day the shadow falls to the west of this point; later, it falls on the eastern side. The dial-plate is carefully graduated according to well-known rules, which we need not stop to consider, and thus, if the dial has been correctly made, any hour between sunrise and sunset may be ascertained by consulting it on a bright day. *Horas non numero nisi serenas* (I only count the hours of sunshine) was an ancient dial motto. We have spoken only of the horizontal sun-dial, but in the vertical dial the principle is precisely the same; the style must in all cases point to the Pole star.

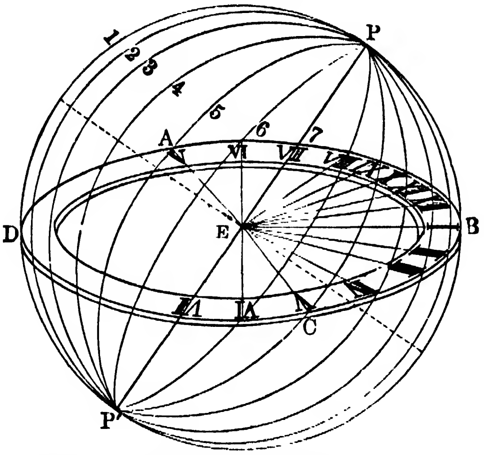

Fig. 1.—Showing the Principle upon which a Sun-dial is constructed.

Fig. 2.—The Gnomon.

It will be obvious from what has been stated that a sun-dial made for London would be useless for either Paris or Edinburgh. The altitude of the Pole star varies with the latitude,* and hence is greater at Edinburgh and less at Paris than at London; and as the style must always point to the Pole star, the angle it makes with the dial plate must vary with the latitude. Again, a little consideration will show that before clocks and watches came into use there would be no such thing as Greenwich time. At the present day, no matter in what part of the British Islands we may happen to be, we regulate our watches by Greenwich time, which can always be ascertained at the nearest railway-station. But when dials had to be depended upon, different towns would have different time. London time would differ from that of Bristol, Glasgow from Edinburgh. It has been already stated that a place fifteen degrees to the east or west of Greenwich has noon an hour earlier or later, as the case may be; and if fifteen degrees make an hour's difference, one degree will make a difference of four minutes. Thus, it is noon at Greenwich eight minutes before noon at Liverpool, and five-and-twenty minutes before it is noon at Dublin. Of course people might have agreed then, as now, to accept Greenwich time as the standard; but then where would have been the use of their sun-dials? Probably a uniform standard of time was not so necessary two or three centuries ago as it is now, with our railways and telegraphs and all the complex life of modern civilisation. A survival of the old custom of each town having its own local time still exists at Ipswich, where the town clock indicates local time, and is therefore always about four minutes before Greenwich time.

Suppose some bright day, about noon, we come across a sun-dial, and have the curiosity to examine it, and to compare it with our watch or the neighbouring church clock. If the dial indicate the hour of twelve, the chances are that it will differ a few minutes—perhaps as much as a quarter of an hour—from Greenwich time. Part of this difference may probably be explained by what was said in the last paragraph, but not the whole of it. If we look at a dial in Greenwich itself, we shall find that it seldom exactly agrees with the clock; and if we examine it at intervals for a week or two we shall find that the time indicated varies in a remarkable way. Thus if we examine the sun-dial early in March, we shall find it about ten minutes slow when compared with a clock; a month later the difference will be only about one minute slow; in May we shall find it three or four minutes fast. The question naturally arises, Which is right, the sun or the clock? At first we incline in favour of the sun, for he is the recognised ruler of the day, and besides he has no complicated system of wheels to get out of order. But let us not decide hastily.

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* "Ocean Sign-posts:" "Science for All," Vol. I., p. 221.

The apparent daily motion of the sun we know is only apparent; it is caused by the daily rotation of the earth upon its axis; but this also causes an apparent movement among the stars. Is their motion regular, or does it seem to vary like that of the sun? Suppose on some clear night we notice a bright star in a line with a church spire, the top of a tree, or some tall chimney, and carefully note the exact time as well as the exact position. If we look for that star the next evening, we shall observe it in the same position probably a little earlier than we expected. If it was ten o'clock the night before, it will want four minutes to ten now. And if we continue our observations night after night, we shall find that it always occupies exactly the same interval of time in returning to the place where we first observed it. This interval is 23 hours 56 minutes, or very nearly. Thus at the end of a fortnight we may look for the star at nine o'clock instead of ten; at the end of a month, about eight o'clock. Here, then, is another difficulty. The apparent motion of both the stars and the sun is caused by the earth's rotation; the stars complete a revolution in 23 hours 56 minutes; the sun requires twenty-four hours. How do we account for this difference of four minutes? and what is the exact time which the earth requires to make one revolution upon its axis? Now we must remember that the apparent motion of the stars never varies, while the apparent motion of the sun does vary, as the sun-dial proves. Both of them are caused by the earth's rotation, and

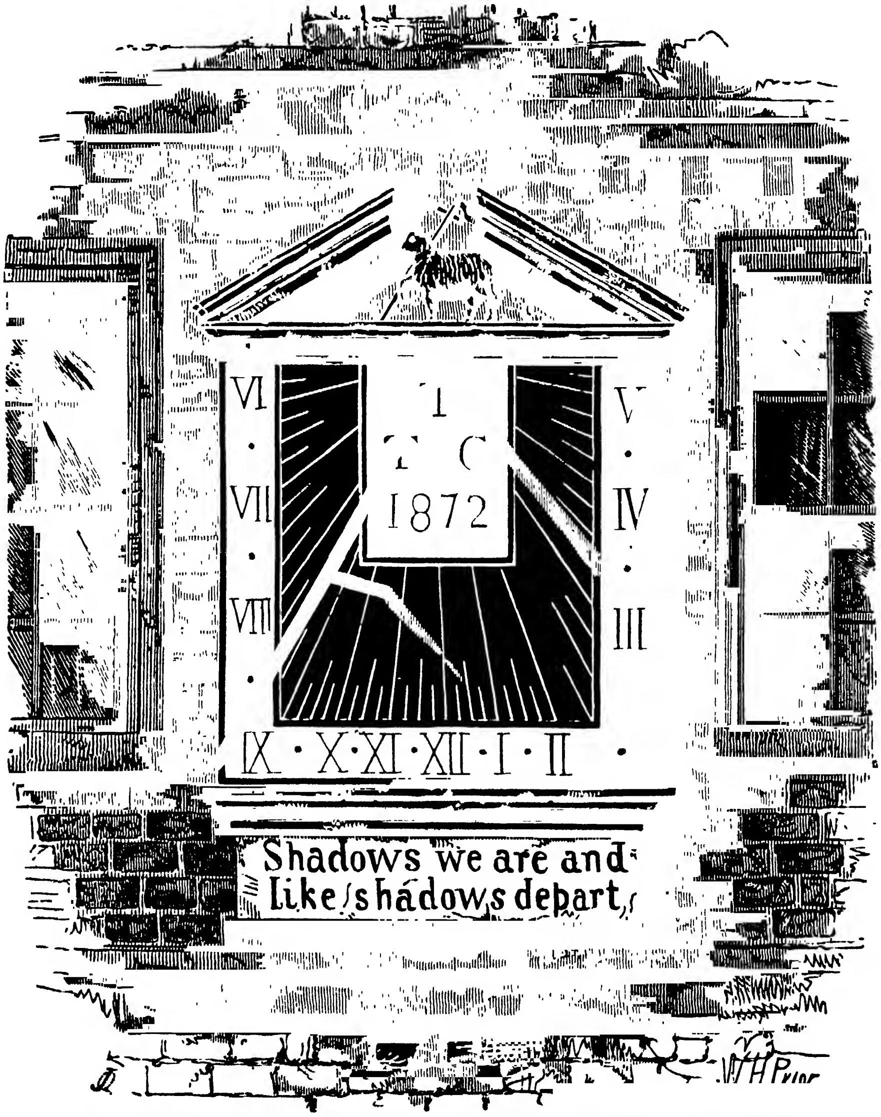

Fig. 3.—Sun-Dial in the Temple, London.—(*From "Cassell's Old and New London."*)

this rotation, it is natural to suppose, is uniform. If we watch a top spinning we see that for a time its motion is perfectly uniform; there is no change from quick to slower and then again to quicker motion. The rotation is gradually overcome by friction; if it were not for this, once started it might spin on for ever. The earth spins round just like a top, but there is no friction, and hence it goes on with a uniform motion from day to day, and from year to year. The exact time it takes to make one revolution is that indicated by the stars—23 hours 56 minutes. This is called a *sidereal* day.

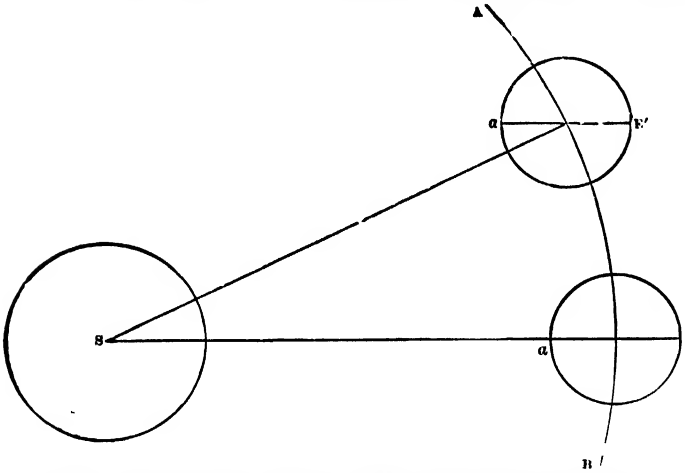

Fig. 4.—Illustrating the difference between a Sidereal and a Solar Day.

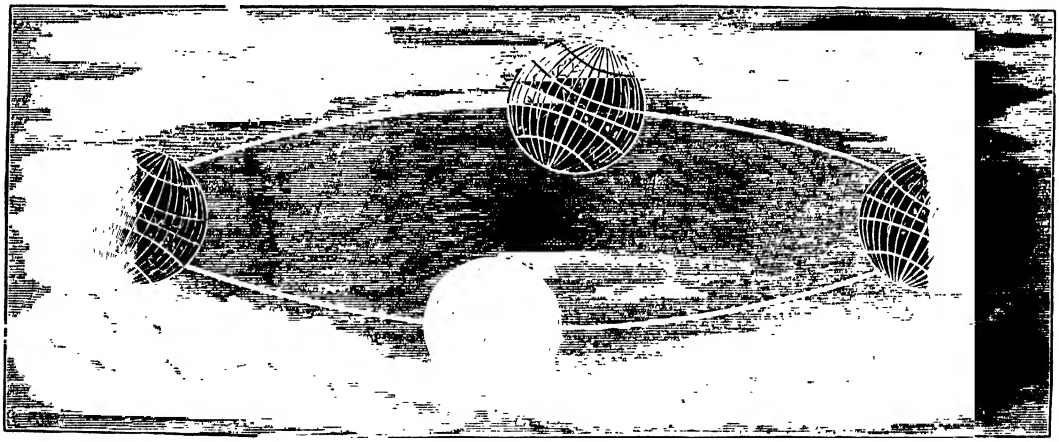

Fig. 5.—The Seasons.

But now two other questions arise. Why is a solar day about four minutes longer than a sidereal day? And why do solar days vary in length?

We know that the earth has two motions: besides the diurnal or daily motion on its own axis, there is an annual motion round the sun. It is this annual motion which causes the difference between solar and sidereal days. This may be explained by a diagram. Let A B (Fig. 4) be a portion of the earth's orbit, and E, E′ the earth in two different positions. Suppose when the earth is at E that an observer at *a* sees the sun on the meridian; then it is evident that if the earth were stationary in its orbit the point *a* would, by the earth's rotation, be brought round to the same position again in twenty-three hours fifty-six minutes, and the solar days and the sidereal days would be of the same length. But while the earth is making one revolution upon its axis it is also moving forward in its orbit, and has reached E′. An observer at *a* will not now see the sun on the meridian, but a little to the east, and the earth must turn a little more to bring the sun on to the meridian, and it requires about four minutes to give this little extra turn. Hence it will be seen that in a solar day the earth makes rather more than one revolution upon its axis. It might be thought that the movement of the earth in its orbit would also affect the position of the stars in the same way. But these bodies are at such immense distances from us that the movement of the earth from one side of its orbit to the other causes only the very slightest change in the apparent position of even the stars nearest to us.

We have now to consider the second question—Why are not the solar days all of the same length? There are two reasons for this. First, because the motion of the earth in its orbit is not uniform. Secondly, because the ecliptic does not coincide with the celestial equator. The first cause is easily explained; the second is rather more difficult to understand.

In the annexed diagram (Fig. 5) we have a representation of the earth in different parts of its orbit. The positions A and C are called respectively the summer and winter solstices; B and D, the equinoxes. The earth's orbit is not a perfect circle, but an ellipse. In winter we are three million miles nearer the sun than in summer. Some may think that if this statement be correct we ought to have warmer days in winter. But the heat which we receive from the sun depends very much upon the direction of its rays. We all know that it is much hotter at noon than early in the morning. In summer, the sun's rays are more vertical than in winter; hence the days are warmer. Now, just as a falling stone moves more quickly as it approaches the ground, so the earth moves more quickly in its orbit as it approaches the sun. In the winter months, therefore, the earth is moving more rapidly than at any other time; in the summer months more slowly. A glance at Fig. 4 will show that this must make a difference in the length of solar days. The difference in length between a solar and a sidereal day depends upon the distance from E to E′. If the earth's annual motion were uniform, this distance would always be the same; but since the earth's motion is not uniform, this distance varies, and consequently the length of the solar days must vary.

But even supposing the earth's motion in its orbit were perfectly uniform, there is another circumstance which would cause the solar days to vary in length. In Fig. 5 the straight lines drawn through the globes represent the inclination of the earth's axis to the plane of the ecliptic. By ecliptic we mean the apparent path of the sun among the stars caused by the earth's annual motion. The earth's orbit lies in the plane of the ecliptic—that is, on the same level—but a glance at the diagram will show that the equator does not lie in this plane, but is inclined to it at a considerable angle. At the summer solstice the sun is vertical at a point 23½° north of the equator; at the winter solstice, 23½° south; at the equinoxes it is vertical at the equator. In an artificial globe a circle is sometimes drawn to represent the sun's path. When this is the case, we see that it bisects the equator in two points, and recedes from it on either side to the tropics of Cancer and Capricorn, which are 23½° north and south of the equator, respectively. The ecliptic, however, we must recollect, is not an imaginary circle upon the earth, but in the heavens; and there is also a circle corresponding to the equator called the celestial equator. These two celestial circles, however, have the same inclination to each other as the circles sometimes drawn upon the artificial globe. Let the circle *a c d e* (Fig. 6) represent the celestial equator, and *b a′ b′ f*, the ecliptic. Now, owing to the earth's annual motion, the sun appears to travel round the ecliptic in the course of a year. If the earth's motion were perfectly uniform the distance travelled by the sun along the ecliptic would be exactly the same every day, but its progress eastward would not always appear the same. All measurements to the east and west have reference to the equator, just as all measurements to the north and south have reference to the poles. A glance at the diagram will show that the distance *a b* is not the same as *a c*, so that near the equinoxes the sun's apparent daily motion to the eastward is less than the average. On the other hand, at the solstices, the distance travelled by the sun in one day—from *a′* to *b′*—is the same when measured on the celestial equator. As a matter of fact, solar days near the equinoxes are twenty seconds shorter than the average, and at the solstices twenty seconds longer.

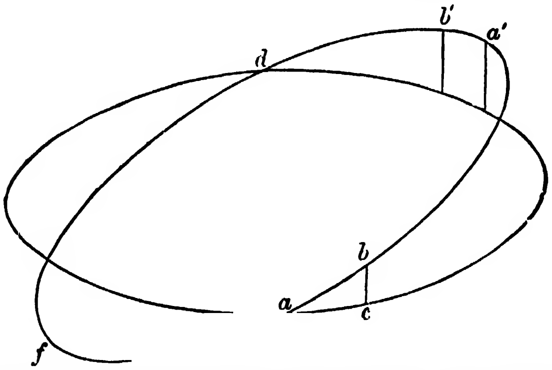

Fig. 6.—Showing the inclination of the Ecliptic to the Celestial Equator.

Thus we see that even if the motion of the earth in its orbit were uniform there would be a difference in the length of solar days; but the motion, as we have seen, is not uniform. The consequence of the two causes combined is that we never get two solar days together of exactly the same length. They do not vary from each other more than about fifty seconds, but this difference may go on accumulating for weeks together, so that sometimes there is as much as sixteen minutes' difference between solar time and Greenwich time. Greenwich time is the average length of the solar days, and this is exactly twenty-four hours. At certain periods of the year a number of short solar days may come together, and then the sun is behind the clock. At another period a number of long solar days come together, and then the sun is before the clock. There are only four days in the year when the clock and the sun-dial agree. These are April 15, June 15, August 31, and December 24. The difference between solar time and Greenwich time is called the *equation of time.* It can be calculated beforehand for every day in the year, and is sometimes printed in almanacks, and occasionally on the face of large dials. In order to make use of this table we should notice carefully the exact time indicated by the sun-dial; then, turning to the table, find out whether the sun is before the clock or behind, and how much. If, then, we make the necessary addition or subtraction, we get correct time, and can then test our watches, or the neighbouring church clock.

The earth completes a revolution round the sun in 365 days and a quarter, or, more exactly, 365 days, 5 hours, 48 minutes, 49 seconds. The year is divided into months, and these, as the name indicates (Saxon, *monath*, from *mona*, the moon), were originally, in this country at any rate, regulated by changes in the moon. The exact time, from new moon to new moon, is 29 days, 12 hours, 44 minutes, and 2·87 seconds; so that, in round numbers, we may say 30 days. But twelve months of thirty days each would only give us 360 days; to certain months, therefore, we assign thirty-one days, to make up the complete year. We obtain the names of the months from the Romans, who originally only had ten months in the year. We can find a trace of this fact in the names September, October, November, December—which mean the seventh, eighth, ninth, and tenth months respectively. It was soon noticed, however, that ten months were not sufficient, and two more, January and February, were added, which originally had twenty-eight days each. The number of days in January was subsequently raised to thirty-one, but February still retains its twenty-eight days. In the time of Julius Cæsar the Roman calendar had got into great confusion. Among other irregularities, the vernal equinox (March 21st) was almost two months later than it ought to be. To remedy this, two months were inserted between November and December, so that that particular year (B.C. 46) had fourteen months. The number of days was correctly fixed at 365¼, and to get rid of the quarter it was decided to *intercalate*—that is, to interpose, a day between the 23rd and 24th of February. This was done by counting the 24th of February twice. Now the 24th of February was then called *sextilis*, or sixth, that is, the sixth day before the 1st of March, and when this day was reckoned twice the year was called *bissextile*, or double sixth. We add an extra day to the month instead, and call it *leap* year. The reason for this name seems to be that in ordinary years Christmas day and other fixed days are one day later each succeeding year, but in leap year they are two days later; there is thus a leap over one day. The efforts of Julius Cæsar to reform the calendar were commemorated by the name of one of the months, which was changed from Quintilis to July.

But we have seen above that a year is not exactly 365 days and a quarter, but about eleven minutes short of this, and though this does not seem much, yet it amounts to a whole day in 130 years. The consequence of this was, that towards the close of the sixteenth century it was found that the calendar again stood in need of reform. An Italian physician projected a plan for its reformation. This, on being presented to Pope Gregory XIII., was submitted to a conference of prelates and learned men and adopted, and in 1582 a papal brief was issued, abolishing the Julian calendar in all Catholic countries, and introducing in its stead the one now in use, under the name of the *Gregorian*, or reformed calendar. It is also sometimes called the *new style*, to distinguish it from the Julian, or *old style*. The chief alterations were these: ten days were dropped after the 4th of October, 1582, and the 15th was reckoned in immediately after the 4th. To prevent any error in future, every 100th year which, by the old style, was to have been a leap year, was now to be a common year, the fourth excepted. Thus, 1600 was to remain a leap year, but 1700, 1800, and 1900 were to be of the ordinary length, and 2000 a leap year again.

For a long time, however, the Protestant countries of Europe would not adopt the new style, and it was not until 1751 that England did so. In that year the famous Lord Chesterfield introduced a bill into Parliament, and the measure received the royal assent. But it met with much opposition out of doors. The great body of the people regarded the measure as impious and popish, and as eleven days had to be omitted in the month of September so as to bring the calendar into unison with the equinoxes, people had an idea that they were being robbed of eleven days. By this bill, also, the year was made to commence with the 1st of January instead of March 25th, as it had done previously. Russia, and those countries which belong to the Greek church, still follow the old style, and hence in Russia Christmas Day falls on what we call January 6th, for the discrepancy between the old style and the astronomical year now amounts to twelve days.

A curious attempt was made at the time of the French Revolution to introduce an entirely new calendar. The year was made to consist of twelve months of thirty days each, and to complete the full number five fête days (in leap years six) were added to the end of the year. Each month was divided into three parts, called *decades*, of ten days each. The time fixed for the new reckoning to commence was the autumnal equinox (September 22nd) of 1792. The old names of the months were dropped, and new ones, descriptive of the time of year, adopted—such as windy month, rainy month, foggy month, harvest month, and fruit month. An attempt was also made to carry the decimal mode of reckoning into the hours of the day; thus the day was divided into ten parts, and these subdivided into hundreds and thousands. This, of course, involved an entire change in the dial plates of clocks and watches, and a decree was issued to this effect. But the new mode of reckoning, as might be expected, perplexed and puzzled ordinary people, and the attempt had to be abandoned; and in 1805, when Napoleon became emperor, the entire calendar was abolished, and the Gregorian calendar re-established.

VENUS AND THE TRANSIT OF 1882.

By Professor S. P. Langley,

Director of the Allegheny Observatory, Pittsburg, U.S.A.

We do not know when the bright planet of our evening and morning skies was first distinguished by its motion from other stars, though it was called under two different names (Phosphorus and Hesperus) by the earliest observers, who mistook it for two distinct objects, one seen before sunrise and the other after sunset. The discovery that these apparently twin attendants on the Sun are really one belongs to a later, though still far remote, period. It is said that an observation of Venus has been found (recorded on an earthen tablet now in the British Museum), which dates from nearly six hundred years before the Christian era; but we must pass over a long interval in the history of the planet, occupied only by a few observations of Greek and Arabian astronomers, to find it attracting its first special interest for us at the time of the invention of the telescope.

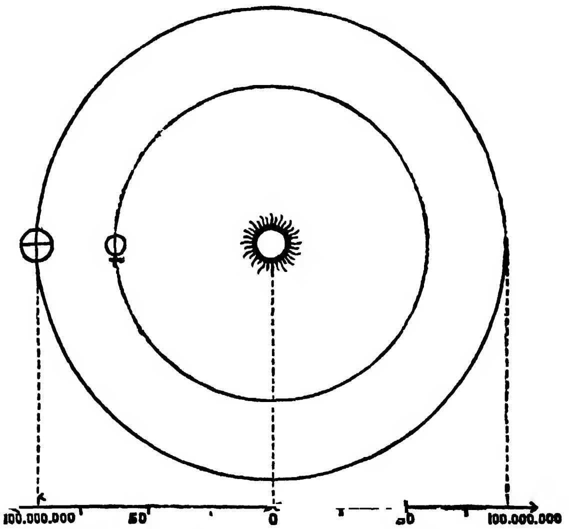

Fig. 1.—Orbits of the Earth and Vénus, showing the scale of the Solar System.

It had been objected to the theory of Copernicus, which made Venus an interior planet (Fig. 1)—one, that is, revolving between the Earth and the Sun—that, in this case, it should show phases like the moon's, and, according to somewhat uncertain tradition, Copernicus replied that such was in fact the case, and that these changes would one day be distinguished. However this may be, it is certain that one of the earliest revelations of the telescope in the hands of Galileo was, that Venus *did* pass, like the Moon, from a slender crescent when near the Sun, to fuller roundness as it withdrew from it. When this most interesting fact was discovered by him, he was divided between the wish to withhold the news of it till he could make more complete observations, and the fear that if he kept silence some one else might anticipate him in the announcement. In our days a scientific man, under such circumstances, would probably write the history of his discovery, and deposit it, under seal, in the custody of some learned society, so that he might establish his priority if it were afterwards questioned. Galileo solved his dilemma by another means then in use, but which he employed with uncommon ingenuity. There is a familiar game which consists in taking the letters which form some common word, and giving them, jumbled into disorder, to an opponent, who is to arrange them, if he can, to re-spell the word which they compose. Galileo first briefly wrote his discovery in the words, "*Cynthiæ figuras æmulatur Mater Amorum,*" or (freely rendered) "Venus imitates the phases of the moon." He might have simply printed, in irregular order, the letters which compose the above sentence, with tolerable confidence that no one but himself could re-compose them into their true meaning; but he did more, and himself re-composed them into still another sentence, "*Hæc immatura a me jam frustra leguntur, o.y.,*" or, "Things unripe for disclosure, read in vain by others, are read by me," which thus both contained an announcement of a withheld discovery, and a taunt to those who were challenged to read his riddle. Any one who will be at the pains to devise a similar anagram will perhaps be of the opinion that the work is as difficult as the original observation it embodies, if not as meritorious. However this may be, the device served its purpose, and no one has ever disputed Galileo's claim to the discovery. After he saw fit to make it known, other and improved telescopes were directed to Venus, and it was found that the planet was a globe presenting spots on its surface (Fig. 2), and by these it was discovered to revolve, like the Earth, in a little less than twenty-four hours. It is rather remarkable that our more powerful modern telescopes have added very little to what was done by the rude instruments of the early observers. Schröter and one or two others have fancied they saw evidence of mountains existing in the roughness of the "terminator," or boundary of light and shade. Schröter even believed he could measure them, and announced that they were over twenty-five miles high! (Fig. 3.) These observations are very doubtful, however, and, indeed, it is to Italian astronomers, even in later times, that we chiefly owe what knowledge of the planet's surface we possess, possibly because its very delicate mottlings are best seen beneath that transparent southern sky. During the last century it was supposed that Venus had a satellite or attendant moon of its own, but it has not since been recognised; and though there is testimony amounting to what seems almost evidence of its having been seen by numerous skilled observers, it is now generally believed to have never had any existence, though the conflict of opinion on the point has made it one of the enigmas of astronomical history.

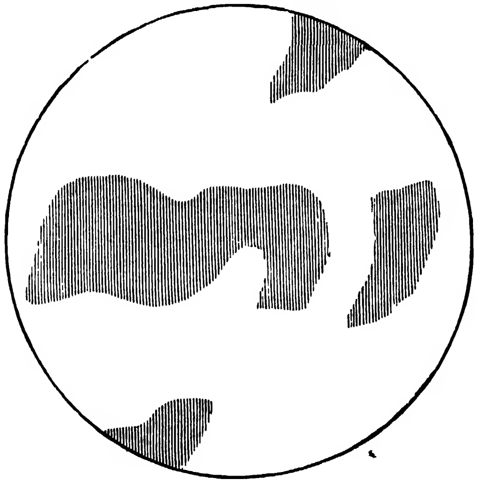

Fig. 2.—Spots on Venus. (*Bianchini.*)

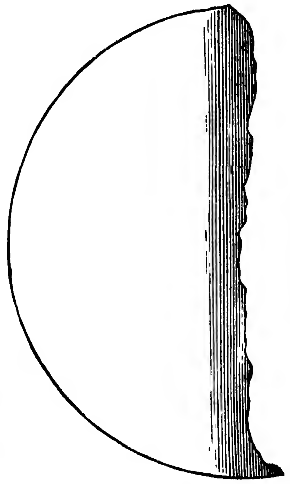

Fig. 3.—Evidence of supposed Mountains in Venus. (*Schröter.*)

Venus has an atmosphere, beyond any doubt, and good observers have even suspected the existence of snow around its northern and southern poles. When the moon is new we often see the outline of its slender crescent prolonged around its entire disc, the rest of which is filled with a faint ashy light. The cause of this phenomenon, which is popularly called "The old moon in the new moon's arms" in the case of our moon, is well known. It is due to the sunlight which its neighbour (our own Earth) itself reflects on to the Moon's surface, but it is very curious that a somewhat similar appearance has been observed on Venus, the outline of the part turned away from the Sun being sometimes very faintly visible. This we cannot possibly account for by the feeble light which the distant Earth, or the outer planets, or the stars shed upon it. It is conceivable that this strange appearance may be owing to the dark side's being visible on the light background of the Sun's corona,* but we must admit our ignorance of the real cause of this peculiarity, which appears to be well attested.

We have now mentioned the principal physical features of the planet, which, however brilliant an object to the naked eye, reveals on the whole less to the telescope than Mars or Jupiter or Saturn; and, were this all, when we have added that it is of about the dimensions of our own Earth, our account of it might be already concluded. But Venus has a wholly different kind of interest for us, which we have not yet touched on, one which is of some importance, and in the year 1882 made the beautiful planet a very general topic of conversation, even among those who care nothing in general for astronomy; and what this is we must now consider.

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* The writer has thus seen the dark body of Mercury just *outside* the Sun's disc.

In doing so it is necessary to refer again to our diagram (Fig. 1), which might be called a map of part of the planetary system. This could have been drawn about as accurately as it is here given even in Galileo's time, with one very important exception—that it then could have had no *scale.* Kepler had discovered the way to make such a map of the solar system, correct in all its proportions, but without a scale, by observing the times in which the planets revolve. His rule (the squares of the times are as the cubes of the distances), which he discovered by immense labour, in guessing and trying all kinds of rules till one was found to work, might be thus expressed: If you want to know the distance of any planet from the Sun, as compared to the Earth's distance, take the time of that planet's revolution, expressed in parts of the Earth's time, square it, and find the cube root. Thus, the Earth's time of revolution being 1 year, and that of Venus a little over $\frac{6}{10}$ths of a year, or, more exactly, ·615, we find that ·615 times ·615 is ·378225, and the cube root of this is ·72 nearly. This, then, is the distance of Venus from the Sun, as compared with the Earth's distance taken as unity; it is, in other words, about 72 per cent. of ours; and in this way, thanks to Kepler, even in Galileo's days, by simply noting the time it took each planet to revolve about the sun, a brief and simple computation would show its distance from the Sun as compared with ours, and so an accurate chart of the whole planetary system could be made. But what *is* our distance? Unfortunately, Kepler's laws tell us nothing about that. We may have a complete map or chart of the solar system, then, without knowing what scale it is drawn on. If, in other words, the distance of the Earth from the Sun, in Fig. 1, is one inch, we do not know from anything yet explained here, whether the inch stands for one million miles, or for a hundred million, nor, consequently, do we know what any other distance is in figures, though we may be sure that all the *proportions* are perfect.

Now it is plain that what we want is the actual distance in miles, of any *one* of these planets from the Sun; for if we know the Earth's to be 90,000,000 miles (for instance), then that of Venus is 72 per cent. of this, which is 64,800,000, and so on for all the other planets.

Astronomers sought diligently, therefore, for a long time to find the Earth's distance from the Sun, but with very poor success.

The difficulty lies in the immensity of this distance, as compared to the Earth's diameter. Since immense distances are well known to be the particular subject of astronomical measures, it may be worth while to see why this one offers such peculiar difficulty.

The *principle* on which we proceed to find the distance of an inaccessible object is entirely independent of that distance, and is just the same whether the object is a tree on the other side of a river, or the far-off Sun. The bee-hunter in the American forests who seeks the tree in which the wild swarms have deposited their honey, proceeds to discover its distance by a simple means, with which he unconsciously works on exactly the same principle as the surveyor or astronomer.

The wild bee when laden flies in a straight line (a "bee-line") to its hoard, which is often miles away. The hunter, provided with a little honey, waits till a wandering bee has supplied itself, and then fixes the direction of its flight by "lining" it with some remote object. This tells him the *direction* (only) of the hive, but not how far off it is. Next he walks away, nearly at right angles to the line the insect took, for a quarter of a mile or so, and again proffers his honey. Some other of the numberless roamers from the same hive supplies himself at this second station and flies homeward. Again the hunter "lines" its flight, which is sure to be in a different direction to that of the first, precisely because both are tending to the same place, and the amount of change in the direction shows whether this place is near or far. The two lines must meet somewhere, and in one point, like the two sides of a capital Λ (disregarding the connecting line of the letter). If it is far off, the Λ has long sides and a sharp angle; if near, short sides and a wide, open angle. (See Fig. 4, where, in the first (A) illustration, *l s′ r* is the sharper, and *l s r* the obtuser, angle.) The hunter can roughly estimate the distance to the point then, when he knows whether the angle between the sides is acute or obtuse; and this he learns without going there, from the difference of the two directions, which just equals it, as will be readily seen. The length between his two stations is called a "base-line" (it is the distance between the two legs of the Λ). The angle at the summit of the Λ is called by astronomers the "parallax." For a given base-line then a distant object has a small parallax and *vice versa*, so that it is easy to see that a very small parallax implies a very great distance, and it may be as readily seen that what the hunter does roughly, a geometer might do exactly, or that it is possible by exacter calculations to tell *just* how far off an object is, if we can learn its precise parallax.

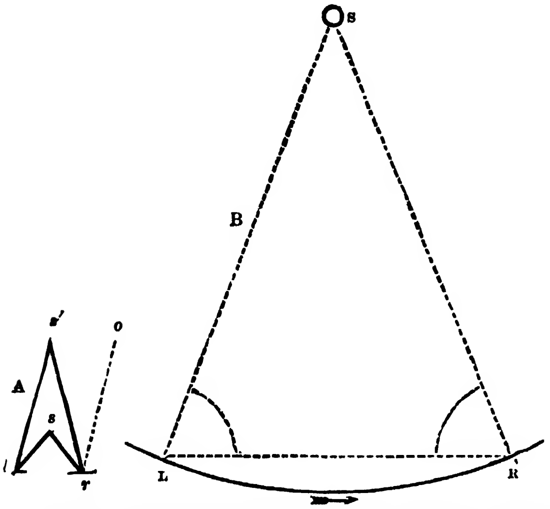


Fig. 4.—Illustrating the Effect of Large and Small Base-line.

The distance of an inaccessible object, then, is measured on quite the same principle by a surveyor, who employs instruments for the purpose, and calculates where the hunter roughly estimates. Thus, let S, in the second (B) illustration of Fig. 4, be a distant tree, and L the place where the surveyor first stands. He lays out a line of measured length, L R (the "base-line"), finds, while standing at L, the precise direction of S (*i.e.*, the opening between L S and L R), and then repeats the process while standing at R, and looking thence at S and back to L. The angle between L S and R S is thus found without going to S, where they meet, and this being known the lengths L S and R S are fixed. If now we take, in the same figure, S to mean the Sun, and L and R to be successive positions of the Earth in its annual orbit, though the principle remains quite unaltered, it cannot be applied in the same way, because if L be the station which the Earth occupies at any moment, there is nothing to distinguish R, the point in the void of space it will occupy later, nor when the Earth has moved on to R is there anything left to mark where it formerly passed at L. The motion of the Earth round the Sun is then no help to us, and we have to give up this way, and try to see whether it is possible to apply the same principle within the limits of the Earth itself. The task is now immensely more difficult than if we could use two distant stations, for it was the different *directions* of the lines drawn to S from the stations L and R which enabled the hunter to find the hive, or the surveyor to measure the distance of the tree. The amount of this difference for a given distance of S depends, as we have explained, on the distance between the stations L, R (the "base-line"); and if this base-line were to be reduced to a mere dot, evidently the two lines drawn to it from S would almost merge into one, and there would cease to be any sensible difference in their direction. The third (C) illustration of Fig. 4 represents the Earth as a base-line, with the Earth the size of a pin's head; but the actual proportion to the Sun's distance would make it far smaller—smaller than the least visible dot.

This difference of direction, as we have already said, is called by astronomers "parallax," a word which is used by them so often, and is so important, that a further illustration of its meaning is not superfluous. We cannot measure the distance of the Sun without a base-line of some kind; we cannot get off the Earth to lay down a long one; and hence we must work, if we work at all, under the disadvantage of a base so small that it—even the longest we can get by going to two opposite sides of our globe—is a mere dot in comparison with the Sun's distance. If the space between a man's eyes stand for the distance between the two most widely possible separated stations on the Earth, then, on this same diminutive scale, the distance of the Sun would be over *half a mile*. The two lines drawn to the eyes from a point representing the Sun's centre would be almost parallel; either would have about the same direction as the other, and the difference of their directions (the "parallax") would be almost nothing.

There is no way out of this difficulty: we must measure, if at all, under just the same conditions as a man would deal with who was called on to find the exact distance of a point half a mile off without moving from where he stood. The actual methods used by astronomers in determining this minute solar parallax by means of Venus, are highly refined, and the processes tedious, but the underlying principle is of the utmost simplicity, and any reader who cares to understand it may do so. Let any one hold up a finger between his eyes and the window, and as near the face as he can distinctly see it (Fig. 5). Keeping the head and the finger motionless, let him close the left eye, and using the right, notice the part of the window the finger appears to cover, D, and next repeat the observation with the left eye, while the right is closed.

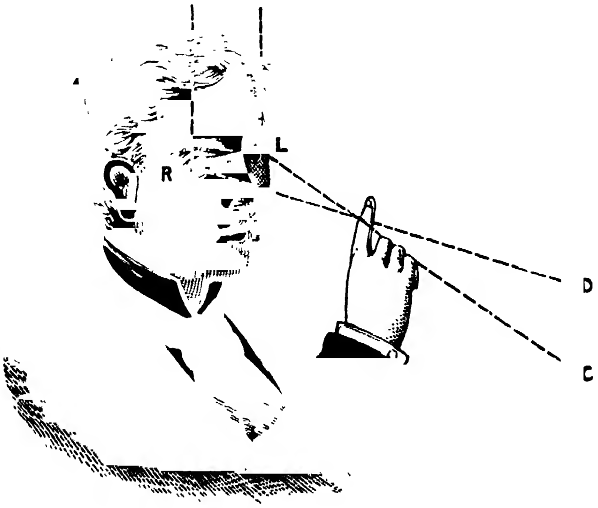


Fig. 5.—Illustration of Parallax.

The finger will now be seen to cover a quite different spot, C, though neither it, nor the face, nor the window has moved. This apparent angular displacement is due to the different direction in which the finger is seen from two different points of observation, *i.e.*, the two eyes; it is, in other words, the "parallax" of the finger; and if this be now held at arm's length, it will still be displaced, but obviously less than before, since the two lines drawn to it from the two stations of observation (the two eyes) are now more nearly parallel, and the "parallax" is smaller. This unfamiliar word, therefore, covers a familiar thing. The "parallax" of the finger is, in still other words, the angle under which our two eyes would be seen by the finger, if that could be imagined to look at *us*. It is plain enough, as we repeat, that these things, distance and parallax, are so linked together that neither can change without a change in the other, and that a *small* parallax implies a *great* distance, as a small angle of the Λ implies long sides, though the object may be so far off that it does not apparently shift its place at all, in which case the point of the Λ is so distant that its two sides are almost parallel, and the only conclusion we can draw is that the object is very remote indeed. Looking at some distant object, such as the corner of a building across the street, we shall see it then appear to move very little, whichever eye we use; that is, its "parallax" can hardly be observed. We might, even in this case, get an idea of the amount of parallax by taking advantage of a very rare event in our streets—the passing of a body with extreme slowness and regular motion, such as when some great mass like the obelisk in New York, or that on the Thames Embankment in London, is drawn along by a windlass with a steady but almost imperceptible movement; for clearly this slow-moving body would, if coming from left to right, cut off the sight of the opposite corner from the left eye before it eclipsed the view from the other, and the small "parallax" would thus be made sensible; but the application of such a method as this must evidently be very rare.

The conclusion to which astronomers came in the beginning of the last century, about the Sun's parallax, was that it was immeasurably small. Copernicus and Tycho Brahe, following still earlier computers, had estimated that the Sun was at least 5,000,000 miles off. Kepler called it at least 13,000,000 miles, and every measure, as observation grew more accurate, only went to show that the "parallax" was, at any rate to the means then in use, immeasurably small, and consequently the Sun's distance immeasurably great. It was already known with exactness, as we have seen, what the proportionate distances of the planets were from the Sun, but the absolute distance of the Sun itself from any one of them was thus lacking. A determination of the *solar parallax*, then—or, in other words, of the distance of the Sun from the Earth, and the consequent knowledge of the scale on which the Universe was built by its Architect—remained wanting.

Under these circumstances, in the year 1716, the celebrated Halley pointed out a method of solving the problem, which depended upon the fact that at certain very rare intervals the planet Venus passes directly between us and the Sun. We shall not attempt here to describe at length the method of Halley, but only to give a clear general idea of the way in which Venus will enable us to solve the difficulty as to the Sun's distance.

Halley proposed, in substance, that two observers should be stationed at opposite sides of the Earth when Venus passed over the Sun's disc (which it does so slowly as to occupy several hours, during all of which time it is distinctly visible as a black spot). Looking towards the Sun, from any point in England or the United States, the left hand is towards the east. Let the observer at the left or eastern end of the Earth's diameter then represent the left eye, in our previous illustration (Fig. 5), and if the planet Venus be moving slowly across the Sun from left to right, as it does at certain rare intervals, it is plain that the left-hand observer will see it touch the Sun's edge before the other one sees it at all (for it is not distinctly visible until it is actually entering on the Sun). If the two observers have compared their chronometers, and know, consequently, when they afterwards meet, how many minutes and seconds one saw it before the other, this will enable us to calculate how long the planet was in crossing from the line of sight of the left observer to that of the right. But as we know just what part of degree Venus moves in this time, we know just how small an angle the distance between the two observers makes as seen from the Sun, and this is the solar parallax, which shows us how far the Sun is away.

Thus, if Venus cross the Sun's centre (to suppose the simplest case), since she is known by common observation to revolve through her entire orbit of 360° in 225 days, in one minute she would move through 4″, that is, four seconds of arc. In the same way the Earth is observed to move through 360° in its year, which gives a motion of 2″·46 in one minute. Then the difference, or 1″·54, is the amount that Venus gains on the Earth each minute, and if the observer at the left-hand extremity of the diameter of the Earth saw it enter the Sun eleven and a half minutes before the other, 11½ times 1″·54, or 17″·70, is the angle which the Earth's diameter fills to an eye at the Sun. It is usual to consider the Earth's radius instead of the diameter, and accordingly half of this, or 8″·85 (corresponding to a solar distance of 92,300,000 miles), would be the solar parallax, and this has been considered, until very lately indeed, to be the most probable value.

It is desirable to have many observers, stationed at different points, which need not be, in practice, at the extremities of the Earth's diameter. Halley proposed, in fact, to have a great many such pairs of observers, stationed at different points on the Earth, lest, he says, "any single observer should be deprived by the intervention of clouds of a sight which I know not whether any man living in this or the next age will ever see again; on which depends the certain and adequate solution of a problem the most noble, and at any other time not to be attained to. I recommend it, therefore, again and again to those curious astronomers who (when I am dead) will have an opportunity of observing these things."

To see why this phenomenon is so rare, we must observe that though Venus revolves in a path interior to ours, she does not come exactly between us and the Sun every year or two (as might be supposed), because her orbit is inclined to our own. Thus, in Fig. 6, let the shaded curve represent the Earth's path about the Sun, and the unshaded one that of Venus. The planes of these two curves intersect in a line which goes through the points which the Earth passes each June and December. Only in these months can Venus, by any possibility, be seen on the Sun; only then on a certain day; and not on that day, unless Venus happens to be there, for she may evidently happen to be anywhere else in her orbit (for instance, at the points marked ♀ ♀), and unless all these events concur she will not be seen "in transit." As thirteen of her revolutions take place (nearly) to eight of ours, if we *do* see her on the Sun, we shall very probably see her there eight years later. Accordingly the transits usually come in pairs eight years apart, but there is commonly an interval of more than a century between. The first transit ever known to have been observed was that on Dec. 4th, 1639, which is supposed to have been seen only by two young Englishmen, Horrocks and Crabtree. Horrocks, who was a clergyman, was unfortunately called away by his professional duties, the transit occurring on a Sunday, so that he witnessed only a part of the phenomenon, and thus lost to astronomy information which would have been highly valuable. The transits which Halley foresaw occurred after his death, as he had predicted, in 1761 (June 6) and in 1769 (June 3). Observers were sent all over the world by the principal governments (the celebrated voyage of Captain Cook to Otaheite was

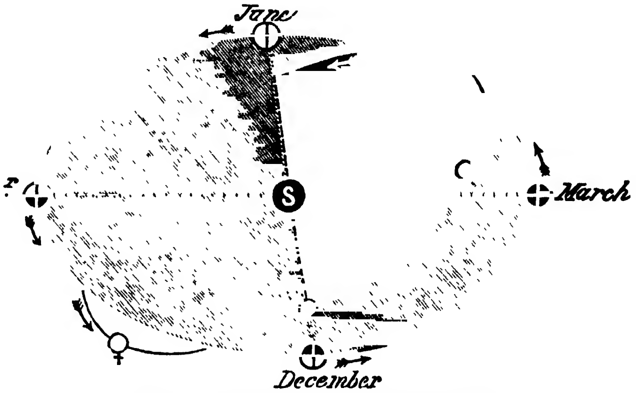


Fig. 6.—Inclination of the Orbit of Venus.

for this purpose), and the result was found to be a solar parallax of 8″·56; in other words, this was the angle which the Earth's radius (not diameter) was supposed to fill if seen from the Sun, and this implies a distance of the Sun from the Earth of about 95,000,000 miles, the value of which was till a few years since to be found in most text-books.

In 1874 the transit occurred again, and extensive preparations were made by Great Britain and other European governments, as well as by the United States. Photography was used very extensively, by taking pictures of the Sun's face, with the planet upon it; but the results from this and other modern means were hardly commensurate with the pains taken; and though observers stationed themselves in the remotest parts of the Earth to witness the event, we cannot be said to have greatly modified our then estimate of the value of the parallax (8″·85) by it. The truth is, modern astronomy possesses indirect means of finding the Sun's distance, such as that from the velocity of light and other methods, which are now believed to be, at least, as trustworthy as that derived from the transits of Venus; and it is possible that the transit of 1882, the last which can be observed for a century, and of which some readers may have been eye-witnesses, may be the last to excite very general attention. Before we describe it, let us consider a method somewhat different from Halley's, which was used in 1882. In Fig. 7 we observe that of two persons, one at the North Pole of the Earth, the other at the South, the northern one will see Venus lower down on the Sun's disc than the other. If Venus then is crossing below the Sun's centre, it would be seen from a station at the North Pole to describe a shorter chord in its transit over the Sun, than when seen from the Southern; and the apparent displacement on the solar disc, bearing a known proportion to the known distance between our poles (the proportion is that of the distance of Venus from the Earth to her distance from the Sun, and these *proportions*, it will be remembered, are known already), we thus, again, have a measure of the solar distance. This is still further shown in Fig. 8, where the approximate apparent size of the planet on the Sun is given by the round black spot, the direction of its motion by the arrow, and the paths in which it will seem to cross to a Northern and a Southern observer are roughly indicated by the dotted lines.

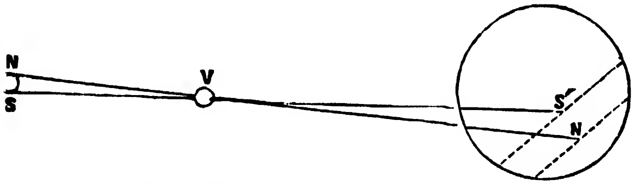


Fig. 7.—Apparent Displacement of Venus.

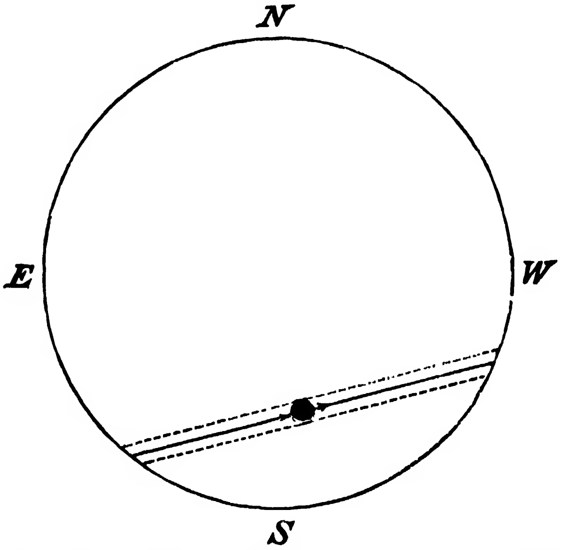


Fig. 8.—Path of Venus on the Sun. Transit of December 6, 1882.

Of course, there is no need of attempting to reach the Earth's actual poles, though it is well to have stations as far apart as is practicable.

All the phenomena of the planet's entrance on the Sun's disc could be witnessed by the residents of the British Islands, and of the Eastern United States, as the two following illustrations (from Mr. R. A. Proctor) will show. Fig. 9 shows the appearance of the Earth as seen from the Sun on the 6th of December, 1882, at the time when the planet is first entering on the disc. It will be noticed that the British Islands are just about to pass out of

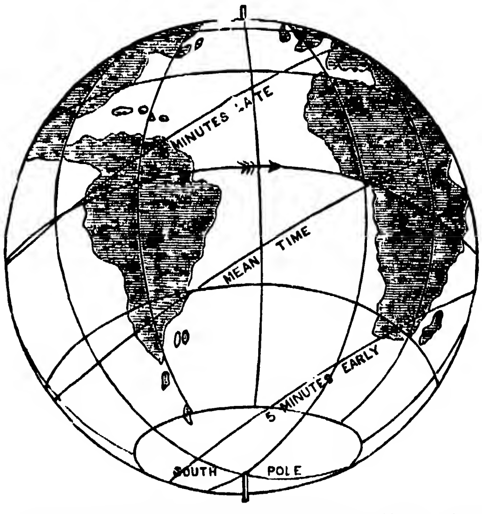


Fig. 9.—Earth as seen from Sun, December 6th, 1882, at beginning of the Transit. (*After Proctor.*)

view, as the globe turns from left to right, as shown by the arrow; in other words, the inhabitants of Great Britain could see the planet enter just before their sunset, and then lost sight of Sun and planet together. Those living in the Canadas, the Eastern United States, and South America not only saw the beginning (Fig. 9) some time after their sunrise, but could witness the whole phenomenon to its close (Fig. 10), at which time the eastern and western coasts of America were both still in view from the Sun, and the Sun, with Venus upon it, was equally (of course) in view from such cities as New York, or Montreal, or San Francisco. The figures upon the globe in each illustration show how much in time the ingress of the planet upon the Sun, or its egress from the Sun, were accelerated or retarded to observers at different points by the cause which we have explained in speaking of Halley's method.

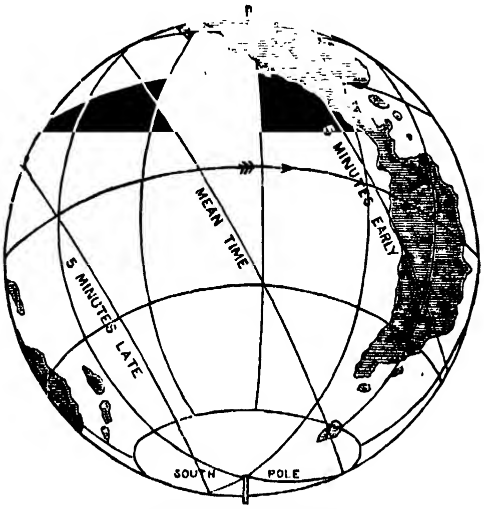


Fig. 10.—Earth as seen from Sun, December 6th, 1882, at end of Transit. (*After Proctor.*)

The value of the parallax already given (8″·85) is, no doubt, very nearly correct; but we believe the general opinion of astronomers now favours a somewhat smaller one, or something between this and 8″·80. If we take 8″·82, which corresponds to a distance of 92,700,000 miles, as the most likely value, we may conclude that it is not probable that astronomers, when they have finally discussed the observations of 1882, will alter it by more than 0″·01 either way; and this angle corresponds very nearly to that filled by the apparent thickness of a *hair*, seen at the distance of one mile! Such is the delicacy of the problem whose determination will fall largely to the lot of American observers in 1882.

Horrocks, the young astronomer-divine, who was one of the two known observers of the first recorded transit, had to regret (as many of his countrymen had in 1882) that the phenomenon was but partly visible to England. It was fully visible to then savage America, and in his account of the transit he could not help bursting into lamentation over the fact, that such an opportunity should be wasted on barbarians! How brief the interval seems since he wrote, as measured on the celestial dial, and how vast the change, as measured in the lives of men! Three times only has Venus since passed before the Sun; and Crabtree, who observed with Horrocks, is believed to have died on the battle-field of Naseby, on a day fruitful in consequences to the principles of those Pilgrim Fathers of America, who carried some of England's best minds and morals to those savage coasts. Yet on the shores of the New World, in our own time, observations of the delicacy just described, and possible only to our latest civilisation, were made upon the transit of Venus of December, 1882.

THE PHOTOPHONE.

By William Ackroyd, F.I.C., etc.

THE last quarter of a century has been a pre-eminently lucky one, so far as scientific revelations are concerned, and to the long list of valuable discoveries made in it we have to add the new order of facts which has been disclosed to us by means of the photophone, an instrument which enables one to transmit speech by means of sunbeams. The evolution of the instrument has been singularly rapid, as the primary fact which led to its invention was discovered only a few years ago at Valentia Bay. It happened in this wise. The well-known electrician, Willoughby Smith, required some substance which offered a high resistance to the flow of electricity for use in testing at the shore-end of submarine cables, and for this purpose he employed sticks of the metal selenium in glass cases. The resistance of the material was found, however, to be very variable, from some, up to then, unknown cause, as at one time one of these sticks would be a very bad conductor, and then unaccountably become a comparatively good conductor. Thus if *Se* (Fig. 1) represent the stick of selenium in its glass case, with platinum wires inserted at each end, it presented the remarkable phenomenon of allowing electricity to pass through it with varying amounts of facility. It was now found by Mr. May, Mr. Smith's assistant, that the light falling on the bar of selenium was the cause of this extraordinary variability; a stick which offered a certain resistance to the flow of the current in the dark only offering one-half the resistance in daylight.

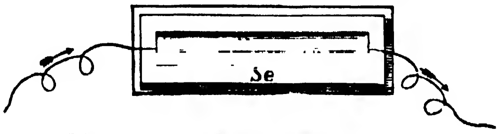
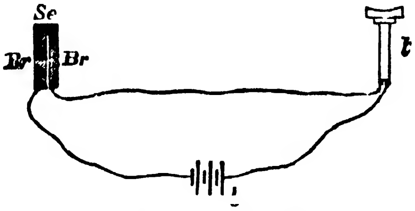


Fig. 1.—The Sensitive Stick of Selenium.



g. 2.—A Selenium Cell.

When this unique fact was made known, it became the subject of investigation by very many physicists, and we have had occasion to refer before to it,[*] when we pointed out that crystalline selenium—that is, selenium which has been well roasted and then slowly cooled—is a better conductor under the influence of light than it is in the dark, and we also explained that a galvanometer had to be used in demonstrating the action of light on this peculiar element. It occurred to Graham Bell, the famous Scoto-American investigator, that one might possibly use the telephone instead of the galvanometer in showing the action of light on selenium; but it was very apparent that before this could be managed some means would have to be devised for rapidly varying the quantity of light falling on the sensitive substance. The reason is plain. A telephone only emits sound when a rapidly variable current of electricity is passing through it, and consequently no sound would be given out so long as the regular current from a battery (Fig. 2, *b*) passed through the telephone in unvarying strength continuously and steadily. Therefore to make a telephone (*t*) give out sound owing to the action of light on the selenium at *Se*, it was plainly necessary to rapidly vary the quantity of light falling on *Se*, so as to produce a rapidly variable current passing through the telephone (*t*). Now this conception seemed to open out extraordinary possibilities. Thus it was apparent that the necessary variation in the quantity of light falling on the selenium might be produced a very great distance away; that, in short, various sounds might be impressed on sunbeams travelling with marvellous rapidity, to be re-converted into sound by the selenium receiver, or "cell," a long way off. An arrangement for this purpose, which was successfully worked by Bell and his friend Sumner-Tainter, is shown in Fig. 3. Sunlight was reflected in the proper direction by a mirror (M), and then converged to a focus by means of an achromatic lens (*l*). At the focus there was placed a revolving disc (*a b'*), perforated with about forty holes, so that when the disc was whirling round there was alternate light and darkness beyond the focus. The rays were now parallelised by means of a second achromatic lens (*l'*), and finally focussed by means of a third (*l''*) on to the selenium cell (*Se*). The conductivity of the selenium was thus rapidly varied, there was a regular change from light to darkness on its sensitive surface, and a change

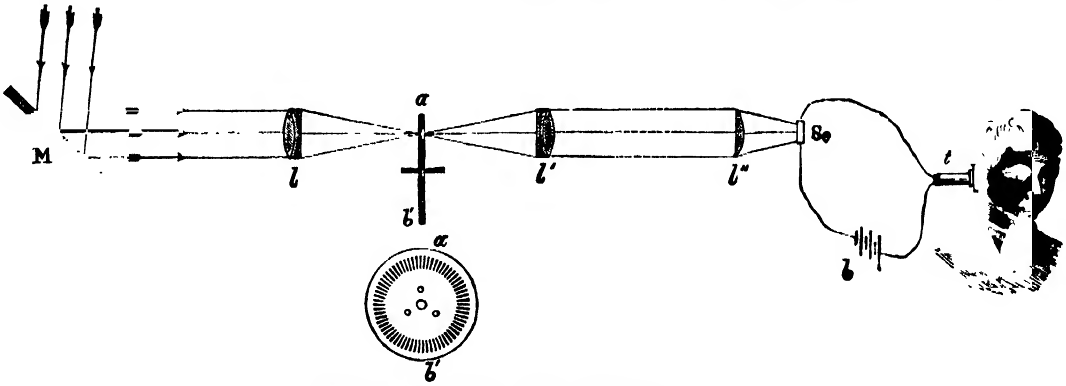


Fig. 3.—A Sonoriferous Beam of Light.

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[*] "Science for All," Vol. III., p. 58.

produced in it corresponding in frequency to musical vibrations, and a musical note was emitted by the telephone (*t*). There was thus devised a remarkable sound-producer, partaking of the nature of the Siren * in its revolving perforated disc, and of the Savart's wheel † in the periodic rapping of ether waves against the selenium cell, but differing most markedly from both in that the active agent was a sunbeam, and the sound-effect depended upon the rapid variation of an electrical current.

Simple as all this may seem, certain practical discoveries were required to be made before such experiments could be satisfactorily performed. Any one who has worked electrically with selenium is aware of the enormous resistance it offers to the flow of an electrical current; he has a vivid recollection of the hours he has spent over the hot-air bath while "cooking" his selenium, to make it crystalline and better conducting, and probably after all, when the selenium has been placed in a dark box (*Se*, Fig. 4) and joined up to the battery (*b*) and galvanometer (*G*), the beam of light reflected from within the galvanometer on to the scale has been scarcely moved when the light from a candle (*c*) has been allowed to fall on the selenium by lifting up the lid of the dark box. It was necessary, therefore, to have a handier way of cooking the selenium; it was necessary, moreover, to devise more sensitive or better conducting cells than had hitherto been used. Messrs. Bell and Tainter overcame these difficulties, for they managed to prepare their selenium in a few minutes, and by employing brass instead of iron and platinum in making selenium cells, as had been done by previous investigators, they reduced their resistance enormously. We shall not describe these cells minutely here, as it will suffice for our purpose to point out that they consist essentially of arms of brass (*Br*, *Br*, Fig. 2) so arranged that a current of electricity can only flow from one arm to the other through a thin film of intervening selenium (*Se*). Their very sensitive selenium cells were now placed in the focus of a lens or paraboloidal reflector, with such results as we shall presently describe.

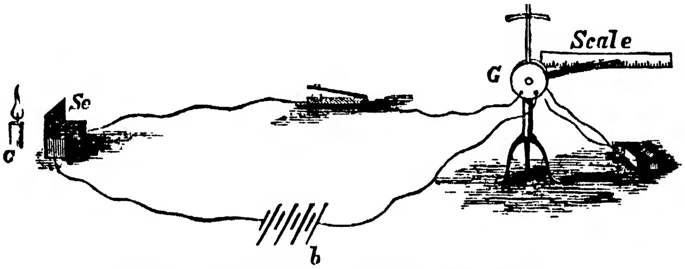

Fig. 4.—The Sensitiveness of Selenium to Light.

We have seen how a musical note could be produced by rapidly intermitting the light falling on the selenium, and Bell now felt convinced that speech also could be conveyed by means of light, for it seemed to him not at all improbable that light might be made to influence or vary the current of electricity passing through the selenium, just as sound-waves are made to influence or vary the current of electricity passing through the carbons in a microphone, and consequently, that just as the telephone reproduces speech in the latter case, so also it might be made to do it in the former. Divination here preceded experiment. The thing required in the first place was a photophone, or instrument which, so to speak, could impress upon a sunbeam the manifold peculiarities of uttered speech, so that the selenium receiving the altered beam would in like manner, by its variation in conductivity, impress the current passing through it in such a way as to cause the telephone in circuit to give out similar sounds to those spoken into the photophone. Messrs. Bell and Tainter devised about fifty different forms of apparatus for this purpose, and they were able by means of them to control or modify a sunbeam at any accessible point of its path. One of these forms of apparatus will be readily understood on reference to Fig. 5. A thin metal grating of fine parallel slits (A) was attached to a diaphragm, which could be set vibrating by speaking into the tube, and it will be understood that this vibration gives the grating a to-and-fro, or backwards-and-forwards motion, precisely similar to the motion given to the style attached to the diaphragm of a phonograph. A

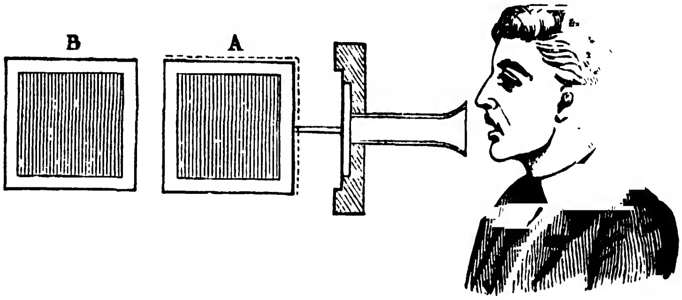

Fig. 5.—One form of Photophonic Transmitter.

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* "Science for All," Vol. II., p. 304.

† "Science for All," Vol. II., p. 303.

second grating of parallel slits (B) was now placed behind the first in the position of the dotted lines. When the grating A is at rest, an unvarying amount of light passes through the two from a lamp in front of them; but when A is vibrating, and its bars are made partly to obstruct the slits in B, it is plain that, under such circumstances, the amount of light passing through the two would vary with the tone and loudness of the voice; that, in short, nearly every peculiarity of voice would be impressed on the beam passing through the slits. If, therefore, a parallel beam were passed through the slits, as in Fig. 6, and such a beam were conveyed on to the selenium cell (*Se*), the quantity of light falling on *Se* would be ever varying while a speaker was uttering sounds at M, and this variation would be a definite one. Bell and Tainter found that the observer at O, in another room, and out of ear-shot, could make out what was spoken at M. Gibberish it certainly was in many instances, for this form of photophone seems to have failed in transmitting consonant sounds; thus Sumner-Tainter, at M, crying out the most unlikely thing he could think of, said, "Put me to bed," and Bell, at O, made it out to be "Good piece of bread."

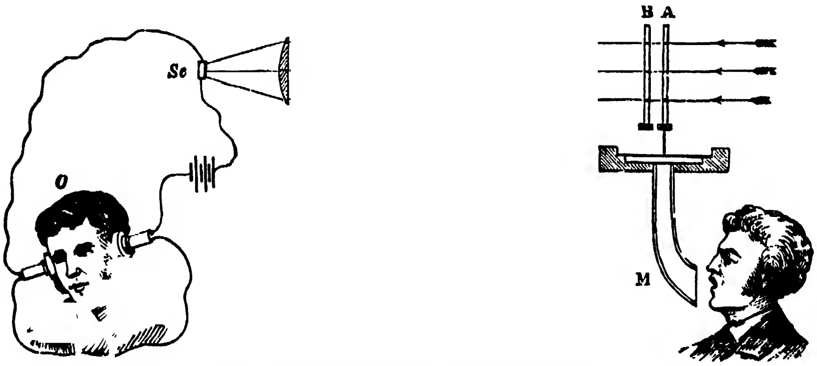

Fig. 6.—Sending Speech by means of Light.

The form of photophone (Fig. 7) which appears to give the most satisfaction is of the simplest nature, since one may speak of it as a thin piece of looking-glass (D) placed at the end of a tube (M). The mirror may be silvered mica, or thin silvered glass, placed at the end of a speaking-tube, so that it may be set vibrating by means of the voice. Such a flexible mirror acts as a very efficient transmitting instrument, for when a parallel beam falls on it, and is reflected, the quantity of light which reaches the distant selenium receiver evidently depends upon the state of the mirror's surface at that moment, whether, for example, it be convex or concave, or a combination of the two.

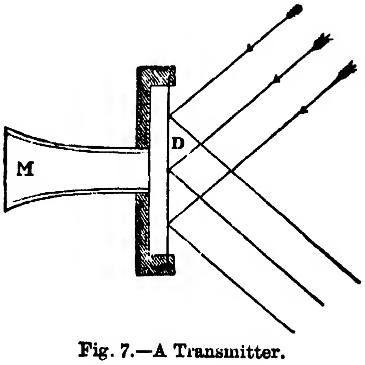

Fig. 7.—A Transmitter.

For reproducing speech at a distance by means of the sonoriferous beam, Messrs. Bell and Tainter have chiefly experimented with sunlight. For this purpose a large beam (Fig. 8) is reflected by the mirror M in the required direction, and then concentrated by the lens L on to the transmitter or diaphragm mirror D. At L^2 a second achromatic lens is placed for making the rays parallel or divergent, just as may be required, and projecting them on to the selenium receiver a distance away. A section of the receiver is seen at R, which is a parabolic reflector with a selenium cell in its focus connected by wires to the telephone (T) and the battery (B). A glass trough is placed at C, containing a solution of alum, for the purpose of sifting heat-rays from the beam, so as to prevent any disturbance which would arise from heating the diaphragm-mirror D. With such an arrangement of apparatus speech has been conveyed beyond ordinary speaking distances, and Bell explained to the members of the American Association for the Advancement of Science at Boston how Tainter and he had made a successful experiment over a distance of about 700 feet. It was in Washington, and Mr. Tainter worked the transmitting instrument on the top of the Franklin school-house, while Bell was at his laboratory in 1325 L. Street with the sensitive receiver arranged in one of the windows. While his friend was at work

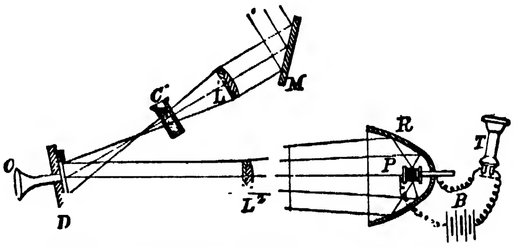

Fig. 8.—Photophonic Transmission of Speech.

at the distant school-house, Bell applied the telephone to his ear, and heard distinctly from the illuminated receiver the words—"Mr. Bell, if you hear what I say, come to the window and wave your hat." In relating this incident subsequently to an English audience, Professor Bell remarked that he need hardly say with what gusto he rushed to the window and made the required signal.

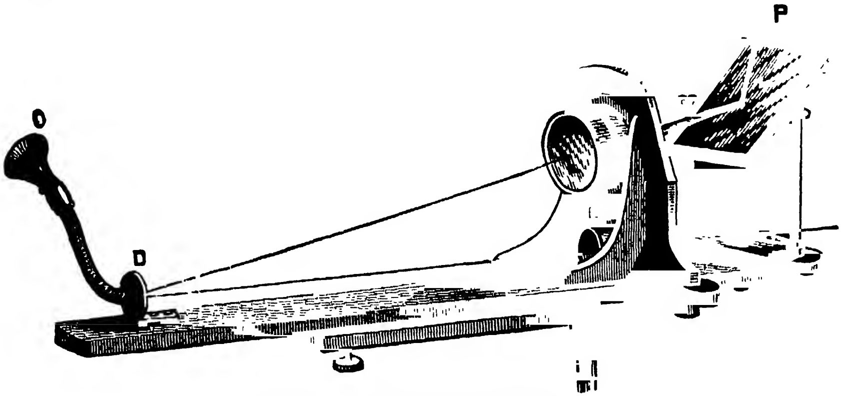

Fig. 9.—Photophonic Transmitter.

The transmitting instrument is shown in Fig. 9, and the paraboloidal receiver in Fig. 10. The preceding paragraph is sufficiently explanatory of the former; and, respecting the latter, it will be understood that there is a sensitive selenium cell in its focus, and from this wires proceed to the outside, and are joined up to the battery and telephone.

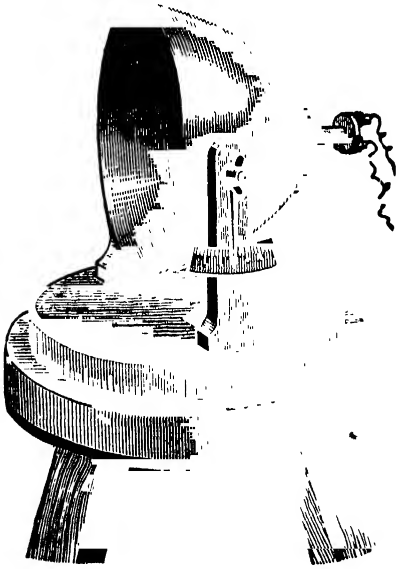

Fig. 10.—Paraboloidal Receiver.

In the course of this investigation Messrs. Bell and Tainter discovered another remarkable fact. They found that a sonoriferous beam possesses the power of causing most substances to emit sound when they are placed in its path, so that the selenium receiver, battery, and telephone could be dispensed with in such photophonic experiments. Thus, when a sheet of hard rubber, or ebonite, was placed in the position of *Se* (Fig. 3), it emitted a distinct note. In earlier experiments of this sort the sonoriferous beam was converged on to diaphragms of the substance placed at the end of a tube, the other end being applied to the ear, and it was not long before it was discovered that the substance of the tube alone would emit a sound when the sonoriferous beam was converged into one end of it. From this it was a natural step to converge the sonoriferous beam into that crooked tube, the ear passage, and upon making the experiment a sound was heard. Perhaps this is the most simple of all photophonic experiments that have been made, the receiver being the ear alone. When new ground is opened out discoveries come thick and fast, and Messrs. Bell and Tainter's investigation has again exemplified the fact, for, in addition to the foregoing discoveries, it has been experimentally shown that solids, liquids, and gases, placed in test-tubes, are efficient sound-producers when a sonoriferous beam is converged on to them (Fig. 11). Chips of wood in this way gave clear audible sounds, and even the smoke from a cigar was an efficient source of sound.

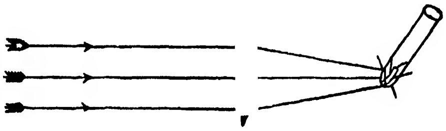

Fig. 11.—A Sounding Chip.

Practical men are now asking—"What is the use of these discoveries?" And, after the manner of Franklin, one might reply by putting another question, "What is the use of an infant?" We only know, so far, that we have been presented with a new instrument which may yet be utilised for all purposes where sunlight is employed in signalling with the heliograph (Vol. III., p. 133), and if nothing more than this is done a vast amount of labour will be saved in the future, because in photophonic, as in telephonic, communications, it is not necessary to learn any code of signals. To the less utilitarian it is already a source of pleasure, in that it has opened out a new line of research of great possibilities. We have learnt that matter in general is susceptible of a change when under the influence of a sonoriferous beam of light; and who shall say that some one of these newly-disclosed facts may not yet form the corner-stone of a vast superstructure of useful knowledge? It has been proposed to investigate the "voice of the stars" with the photophone, and if we should ever be so far successful as to be able to study the superficial tremors of heavenly bodies by means of the light they send earthwards we shall indeed have learnt to interpret the *vox stellarum* in a way no astrologer ever before dreamed of attempting.

THE CRAG.

By B. B. Woodward, F.G.S.,

Secretary of the Geologists' Association.

EVERYONE who has visited Walton-on-the-Naze, or Felixstowe, must have been struck by the wonderful accumulations of shells and their *dêbris* which in those localities go to form the low cliffs of the coast; and, stimulated by the mania for collecting that seizes every seaside visitor, has doubtless commenced to pick up some of the more perfect specimens. Their close resemblance, and in most cases, indeed, identity with the shells now living in the sea below, is at once apparent; but the collector soon realises that the greater number are quite rotten and readily fall to pieces when handled, having lost all their animal matter.* Moreover, they are generally stained a deep red with iron oxide, or rust.

Locally, all such sandy beds containing an abundance of shelly remains are known as "crag;" but geologists, while retaining this general term for the whole set, have subdivided them into three groups. To the middle one of these three the beds in question belong, and are termed, in recognition of their characteristic colour, the "Red Crag."

Inland, gangs of workmen will be found busily employed in the pits dug in these shell-beds, washing and sifting the stuff from the base, and picking out the hard, dark-brown oval lumps that shine when freshly washed as though they had been polished. To these oval bodies the name of coprolites has been applied, from a mistaken notion as to their true origin at the time of their discovery.

In reality they are merely nodules, or concretions, containing so large a percentage of earthy phosphates, that when ground down and properly prepared they form one of the best possible manures for agricultural purposes. On digging down into the London Clay, which hereabouts underlies these shell-beds, similar nodules will be found disposed in layers through the clay, after the same fashion as the flints in the chalk; nor was their probable method of formation essentially dissimilar. In both cases a number of decomposing organisms may be imagined lying scattered over the sea-bottom, half buried in the soft silt, or ooze. These formed centres of attraction, around which the mineral matter prevalent at the time in the water —phosphate of lime in the one case, silex in the other—collected and subsequently hardened.

If the organic matter had no hard parts about it capable of being preserved, none of course would remain; but frequently the phosphatic concretions are found enveloping the fangs of sharks' teeth, or the remains of crabs, &c. That the phosphatic nodules at the base of the Red Crag are merely such of these same concretions as have been washed out of the London Clay, and rolled on the bed of the Red Crag Sea, is abundantly evident not only from their identity in composition, but also because they frequently contain precisely similar fossils.

A cursory glance at a freshly washed heap will show that mixed with these nodules are the almost perfect ear-bones of whales, together with fragments of other cetacean bones and pieces of wood that were in like manner first phosphatised and then rolled on the sea beach. Subsequently many of them lay at the bottom till they were covered with barnacles, traces of which may still be seen adhering to them. In the process of sifting and washing, the workmen constantly come across the teeth of sharks, sometimes as well preserved as though fresh from their original bed of the London Clay. These and the other small fossils they carefully pick out and sell to local collectors and casual visitors. Less frequent, but still tolerably abundant, are the molar teeth of the mastodon, rhinoceros, tapir, hipparion (a fossil relative of the horse), and other animals of the old land surface (or possible lacustrine deposit) which preceded, and was broken up by the advancing waters, its contents being scattered over the floor of the sea.

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* "Science for All," Vol. III., p. 243.

Another formation must likewise have been almost annihilated by the encroaching sea, for thrown out from the nodule heap are some round water-worn sandstones, externally looking very like rough-skinned potatoes, but which when broken open are frequently found to contain the casts of shells and other fossils. The shell has disappeared, leaving a hollow space, whence the name "Box-stones," applied to them by the quarrymen. It would appear that these box-stones are the remnants of an older crag than any yet found on the English coast, and the equivalent, probably, of a stratum situated on the other side of the German Ocean, near Antwerp.

To complete the list of heterogeneous materials congregated at the base of Red Crag, it is necessary to add the large flints derived from the neighbouring Chalk, occasional nodules from the Lias, and boulders of rocks foreign to the locality, that can only have been floated thither from long distances on ice rafts.

This flotsam and jetsam from so many formations clearly indicates what an enormous amount of wear and tear must have taken place before the deposition of the overlying shell-beds, and points strongly to a shallow, tidal sea as the principal agent of destruction and re-deposition : a conclusion which is yet further borne out by the succeeding shell-beds. For the flat pieces of shell do not lie horizontally, but in sets of parallel layers, inclined, now at one angle and now at another, to the general direction of the beds themselves.

This phenomenon is known to geologists as "false bedding," and has been produced by the cross-currents in the water first heaping the fragments up in one direction into banks, or perhaps beaches, and then sweeping half of them down, and piling them up afresh in another direction ; at one time cutting channels through the banks thus formed, at another filling these channels up again.

At the same time, the oblique bedding is sometimes continuous for a considerable distance throughout a given bed. Towards the close of this period, however, there are evidences of a more tranquil state of affairs, as the component layers of the bed assume the normal, *i.e.*, horizontal position.

The shells of which the beds seem in places to be almost entirely composed are, as already stated, in a most friable condition; nevertheless, by searching amongst the fallen *débris*, or "talus," and by digging out masses at a time of the stuff from the sides of the section, be it pit or quarry, some tolerably well-preserved specimens will readily be obtained. Of these, almost the first to attract notice is the well-known "reversed whelk" (*Fusus contrarius*), as it is called, since in this shell the whorls are wound in the opposite direction to that which usually obtains in the whelk tribe, the mouth appearing on the left-hand side of the spire, when viewed in front, instead of on the right. This species or variety, as some consider it, though rare now-a-days, was extremely abundant in Red Crag times, especially at Walton-on-the-Naze, where the dextral form is unknown. These left-handed whelks have, curiously enough, always a smooth exterior, whereas the right-handed ones are as a rule more or less sculptured or ornamented. The lesser members of this large family, the dog-periwinkle (*Purpura*) and the dog-whelk (*Nassa*), are extremely abundant. So, too, are the Naticas; but the chief of the Red Crag Gasteropods is undoubtedly the huge volute (*Voluta Lamberti*), an extinct shell, that attains the length of seven, and sometimes even nine inches.

Amongst the bivalves the Cockle family is well represented, as are also the Tellinas, whilst a species of *Pectunculus* (*P. glycimeris*) is very plentiful. In all, some 230 different species of shells have been found in the Red Crag, and of these 27 per cent. are extinct. They are of a littoral or shore character, and betoken a climate somewhat warmer than that now prevailing in this spot.

Leaving Felixstowe, and proceeding up the River Deben to Sutton, an altogether different kind of crag will be found. From Sutton it extends to Gedgrave, and thence to Aldeburgh (or Aldborough), being best shown in the district between these two last-named places.

In general this crag is of a yellowish or buff colour, and has, therefore, in contradistinction to the foregoing, been termed the "White Crag," but it is more commonly known as the "Coralline Crag," because, instead of fragments of shell, it is largely built up of the remains of those beautiful little organisms called Polyzoa. At Sutton it has been seen resting on the denuded surface of the London Clay, in the same way as the Red Crag farther south. The same phosphatic nodules occurred here at its base ; but they were not so numerous, and did not pay for the working, which was consequently abandoned. From this nodule bed a large block of red porphyry, weighing nearly a quarter of a ton, was dug out.

Since no analogous rock of this description has been found in the British Isles, it may fairly be assumed that it was transported thither by floating ice from a foreign shore—possibly Scandinavia—and deposited in company with many smaller boulders derived from rocks nearer home.

The connection between this crag and the preceding is shown in numerous cuttings, the latter in every case being the uppermost. Not that the succession was a quiet one; on the contrary, the turbulent Red Crag sea cut and carved channels and gullies in and about the coralline beds, afterwards filling them up with the newer material, through which the fragments of the coralline are disseminated.

When undisturbed, the Coralline Crag is about fifty to sixty feet thick, and proves on investigation to be divisible into three series. At the base is a set of calcareous sandy beds full of fossils, here and there very perfect, the pairs of the bivalves remaining united. Then there comes a harder lot, consisting mainly of the calcareous skeletons of Polyzoa firmly cemented together, so as in places to form a soft building stone. False-bedding is a constant character, showing that they were laid down in shallower and more restless waters. Finally, another bed, only a few feet thick, made up of the abraded material of the last, crowns the summit. Upwards of 300 species of shells have been collected from this crag, but of these 36 per cent. are now extinct. Amongst the more common forms are observable *Pectunculus glycimeris*, the smaller edible scallop (*Pecten opercularis*), several pretty species of *Astarte*, and a handsome *Cyprina*, along with key-hole and notched limpets and many other familiar shells.

The Polyzoa are so abundant in some of these beds, and more especially the middle division, that an hour may readily be spent in sifting out a cubic foot of the earth. They are not, as one would at first suppose, judging from their external form, allied to the corals, but to the mollusca, being, indeed, colonies of little animals closely related to the Brachiopods, or Lamp-shells.* They form most beautiful objects under a low power of the microscope, and a few hours out of a summer's holiday spent in collecting them will furnish material for many a long winter's evening of enjoyment. Nearly a hundred species have been found in the Coralline Crag, and out of this number about thirty are still living. From a study of the fossils and the nature of the beds themselves, it would appear that the sea in which they lived was at first tolerably deep (about thirty-five to forty fathoms), but that it gradually became shallower till it changed into the littoral sea of the succeeding Red Crag period; whilst at the same time the climate, comparatively a warm one in the commencement, was gradually cooling down.

Quitting the district round about Aldeburgh, and journeying northward into Norfolk, both these crags disappear, and their place is taken by a series of sands, laminated clays, and shingle beds, with occasional seams of shells. Endless geological disputations have arisen, and interminable "papers" have been written, about these variable beds. Nevertheless a certain amount of order has at length been evolved out of their confusion, and the "Norwich Crag," or "Laminated" Series, is now divided, like the Coralline, into three groups.

Beginning with the lowest: at the bottom come some false-bedded sands, with seams of shells separated by a layer of flints from the underlying chalk—for the London Clay had been denuded of this spot long before the Crag beds were laid down.

This bed of flints, called the "Stone bed," corresponds in position and is analogous to the nodule bed at the base of the other crags. Amongst the rough stones are distributed fragments of the bones and teeth of the mastodon, hippopotamus, rhinoceros, stag, horse, ox, and other animals.

The shells in the Norwich Crag are not so numerous, perhaps, as in the Red and Coralline; still 140 species have been determined, including seventeen now extinct. Periwinkles, cockles, dog-periwinkles (*Purpura*), some Tellinas and mussels are amongst the commoner forms, indicating a more northern, or colder climate. They must have lived in the sandy bays of an estuary, or collection of small estuaries into which rivers flowed, for a number of species of land and fresh-water shells have been found associated with the littoral forms, whence the name "Fluvio-marine" has also been applied to this crag. That the deposition of these strata was, in part at all events, contemporaneous with that of portions of the Red Crag is manifest, because the succeeding middle group of the "Norwich Crag" series rests on the eroded surface of the latter in some places, and on that of the still older Coralline in others.

The Chillesford Sands and Clays, as this second set is called, take their name from the village near which they are best developed, and where they yielded the greater part of the skeleton of a whale. The few shells they contain show a further increase in Arctic forms, and consequent decrease in the temperature of the water; whilst their more tranquil deposition (the layers being horizontal) and comparatively wider extension indicate the further encroachment of the sea. A partial erosion of the Chillesford beds appears to have taken place before the upper series of shingle or pebble-beds (Westleton and Bure Valley Beds) were thrown down on them. Considered by some authors to belong to the glacial period, these shingle-beds are classed by them with that wonderful series of drift deposits which mask so large a surface of the country. No more complicated strata are probably to be found anywhere than these traces of former Arctic conditions in Britain; but their history has already been sketched out in these pages (Vol. I., pp. 33—40 and 69), and need not, therefore, be repeated here. Perhaps a general notion of the relation of these beds to each other may be best gathered by a reference to the accompanying diagrammatic section (Fig. 1).

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* "Science for All," Vol. I., p. 67, Fig. 5.

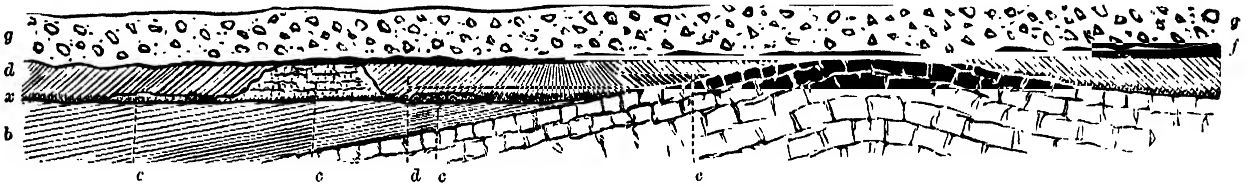

Fig. 1.—DIAGRAMMATIC SECTION TO SHOW GENERAL ARRANGEMENT AND ORDER OF SUPERPOSITION OF STRATA IN EAST ANGLIA.
g, Drift Beds; *f*, Chillesford Beds; *c*, Norwich Crag; *d*, Red Crag; *e*, Coralline Crag; *x*, "Nodule Bed" and "Stone Bed;" *b*, Lower Eocene; *a*, Chalk.

Such, then, in brief, are the principal facts concerning the crags as they now exist; but what is their connected history, and what their true relation in the geological sequence to the London Clay and Chalk, on the denuded surfaces of which they rest? In the view of a quarry section (Vol. I., p. 65) we have a diagrammatic representation of the sort of beds that exist between the Chalk (*a*) and the London Clay (*h*), a small portion of which is shown "faulted down" against the others. Where, therefore, the crag-beds rest directly on the chalk, it is evident that such of those intervening beds as were deposited on that spot must have been destroyed and carried away, and the hiatus thereby still further increased. Over the London Clay, and resting unconformably on it, are two drift-beds (*i* and *k*). Now the crag series, as was seen, passes gradually up into the drift-beds, so that if inserted in their proper place in the quarry section they would come immediately below them, and still rest unconformably upon the London Clay. On referring to the table of strata shown in the Frontispiece to Vol. I., the drift-beds will be seen in their proper place at the top of the ideal section there depicted, and underneath them the formation called "Pliocene," which in England consists entirely of the crag-beds just described. The next formation in descending order is the Miocene, and below that, again, is the Eocene, to the lower half of which the London Clay belongs; so that several hundred feet of strata are entirely wanting between the crags and the rocks on which they rest.

Some faint notion of the enormous length of time that must have elapsed during the period and a half thus recorded in East Anglia may perhaps be gathered if, by way of conclusion, we give a short summary of the events that, judging from deposits in neighbouring areas, must have taken place over this district. The London Clay, it is agreed, is the accumulated sediment of a large river that brought its tons upon tons of mud annually down to the sea, just as many rivers are doing at the present day, and spread it over the bottom of the huge estuary which then occupied the whole of what is now the south-eastern portion of England. That the river drained a warm continental country is abundantly proved by the palm-nuts and other fruits which floated down it, and, becoming water-logged, sank at its mouth, as well as by the remains of river-tortoises, crocodiles, &c., associated with them. Gradually, however, the physical conditions altered, and a sandy deposit ensued, the sea meantime swarming with shells of a tropical character. Considerable patches of these sands remain in the neighbourhood of Bagshot, Surrey, whence they take their name; whilst the hills of Harrow and Hampstead, and the high grounds beyond Epping, in Essex, are capped by small detached portions. They stretched, too, over the South Downs into Hampshire, where they are found again, the intervening district being strewn with the harder fragments (Sarsen stones) that defied the powers of denudation to wash them away. Though the old river made its influence less felt for a time, still it was assuredly not far distant, for the succeeding deposits, which are confined to the Hampshire basin, and are familiar to every visitor to the Isle of Wight, show a return to more purely estuarine, varied with fluviatile conditions, and with these the Eocene period was brought to a close. Altogether these middle and upper Eocenes amount to some 1,500 feet of strata, and must have required considerable time for their formation. Of the ensuing Miocene epoch, on the other hand, but the scantiest vestiges, if any, remain in the British Isles, and yet, as will presently be seen, it was in every respect an important one. The whole of the Isle of Wight beds are now relegated to the Eocene, and there are but three small isolated patches of leaf-beds and lignite-beds which might possibly represent this period. These remains of ancient forests are situated, one at Bovey Tracey, another at Antrim, and a third in the island of Mull; whereas, on the Continent considerable accumulations of fossiliferous strata were in course of formation, but whether any similar deposits were ever laid down in these islands is very doubtful; at all events, no trace of any such has yet been found. It is certain, however, that active volcanoes were plentiful both in these islands and on the Continent. Indeed, the Antrim and Isle of Mull leaf-beds owe their preservation to lava-flows, which, while they destroyed the forests, buried and preserved their remains.

In size, these old volcanoes of Ireland and Scotland must have rivalled, if not surpassed, Etna, but nothing now remains of them beyond the roots. The craters have long since been washed away and disappeared, and the hard crystalline rocks of their deep-seated bases form some of the highest portions of the present land-surface. At this stage of the earth's history, too, widespread movements of the crust took place. The Alps, Pyrenees, Carpathians, and Himalayas received their final elevation; whilst in England the chalk and its superincumbent Eocene beds were thrown into those folds out of which subsequent denudation carved the North and South Downs and the range of chalk hills to the north of London, stripping off the tertiary beds in the process. Nor were these changes effected by sudden or convulsive movements. Spread over centuries, during the greater part of which England was above water and exposed to meteoric agencies, they were brought about by the same quiet processes that are in progress at the present day.

With the advent of the Pliocene period a depression took place over the area now occupied in great part by the German Ocean, and in the sea thus formed the crag-beds were thrown down: first, those near Antwerp, and then the ridge of Coralline Crag. The temperature of the water was favourable to the growth of more southern forms of mollusca than now dwell on the spot, and the sea was probably more open to the south; but in the spring-time the ice floated down from the north, bearing with it boulders of foreign rocks, which, on melting, it dropped to the bottom. Then, by slow degrees, the land rose again to the south, the sea extended to the north, letting in more cold water, and the ridge of Coralline Crag approached the surface. To the south of this bank the now shallow sea piled up the shells of the colder Red Crag period; whilst on the northern side, in the sandy bays of an estuary, or collection of estuaries, the Fluviomarine Crag was forming. But once more the sea claimed its own, and with temperature yet further lowered, crept southward, spreading out the Chillesford sands and clays over the other deposits. Finally, a further depression ensued, ushering in that prolonged Glacial Epoch and its attendant phenomena, of which every one has heard so much, but in reality knows little.

GERMS.

By F. Jeffrey Bell, M.A.,

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If we put into a pot of water a small piece of flesh, and leave it exposed to the ordinary air, we shall find that after a day or two the top of this water is covered by a greyish film, and if we smell the water we shall find it to be what we call "putrid;" we shall say, "This meat is going bad."

Perhaps the most intelligent question which can be asked by one who has made this experiment would be put in something like the following terms: "We know that this piece of flesh in the water was once part of a muscle; we know that in muscular tissue certain activities are, during life, to be observed, which, so far as we know, are characteristic of muscle; we have seen it contract under the excitation of certain nervous influences, and we have seen that that contraction is very different in character from the contractions of cooling bodies. Is, pray, this 'going bad' a characteristic of dead muscle? I should hardly imagine it to be so, for I have smelt dead decaying vegetables. But is this 'going bad' a characteristic—to put the matter much more generally—of matter which is now dead, but which was once living?"

To such a question many would give but one answer: they would say, "Yes, of course; all living matter decays when it is 'dead.'" But the very vagueness of this answer might of itself excite suspicion. Ignorance has recourse always to bold generalisations; science alone bases its answers on a counter-statement of facts.

Suppose, then, such an answer given, and suppose, also, that the questioner has a more scientific habit of mind than his answerer—and this is not hard to suppose, nor will it fall beyond the experience of most of us; suppose him to be a child of Science, who

> "Reaches forth her arms
> To feel from world to world, and charms
> Her secret from the latest moon."

Allow it true of our inquirer, and that he, with his attention attracted by the film of which we have just spoken, brings some of it on a glass slide under the inspection of a fairly high magnifying power. Is it then that he still sees any sign of death? Far from it. He will probably see objects not unlike those shown in the adjoining figure: minute particles, perhaps in active movement, rushing towards and rapidly separating from one another. He will see enough to induce him to believe that he is in the presence of living matter; and he will judge rightly. If he carefully study the small rod-shaped (*Bacterium*) particles (Fig. 1) thus exhibited to him, he may see in them the leading characteristics of life—reproduction of the individual; if he carry on a series of experiments he may see that they use up the nutriment in the water; and he may, again, see them die down.

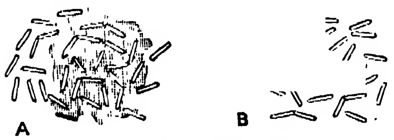

Fig. 1.—Bacterium termo.
A, Partly embedded in the gelatinous film; B, Free.

So far, then the observer would be justified in associating the present case of the decay of the piece of meat with the presence of the *Bacterium*; but he would not be able to generalise upon his present knowledge. Before he could do this he would have to make two other series at least of experiments.

(1.) Remembering the observation of the Strong Man of old on the dead carcase of the lion, he might say with him that out of his meat there had come this living matter; the *Bacteria*, he might say, were *generated* by the meat, just as Samson's lion brought forth honey. Well, granting this: suppose he applied to the meat the best way of killing the living matter within it—no mode is better than that of interrupted boiling. Let then the meat in the water be boiled again and again, and let it be kept from all external influence which might in any way affect the results of the experiment. Look at the water after a week, or, if you will, after a year; the water will still be clear, there will be no film nor any smell of decaying matter.

(2.) If, then, the origin of the *Bacteria* is not to be sought for in the meat or the water of itself: that is to say, neither in water nor meat in which all the living matter existing in it up to the time of the experiment has been destroyed by boiling, let us try another simple experiment, and see if the air itself has anything to do with the matter. Open your flask of meat and water which has been so long clear, and expose it, even for a little, to the air. This experiment will not, unless, perhaps, you try it at the top of an Alpine mountain, have negative results, like the one tried before; in a day or two there will be all the signs and smells of decay, the existence of a film, and the presence in that film of *Bacteria*.

The air, then, has something to do with the decay of the meat: and yet it can hardly be the air itself; this, however, must be tested, and if a small chemical laboratory be at hand, no difficulty will be found in making the experiment. All that one would have to do would be to prepare a flask of meat and water, to boil the infusion so as to kill all living matter within it, and draw into this tube air filtered through cotton-wool, or, better still, through cotton-wool that had been dipped in glycerine. A more elaborate experiment might be made (but this would be much more difficult), in which the air would be so thoroughly heated as to kill anything in it which might be living; were this done, the cotton-wool might be dispensed with. Take, however, the easier case, and draw air simply through the tube with the cotton-wool in it, or, in other words, introduce into your flask of meat and water nothing but air proper: the mechanical compound, that is, of nitrogen and oxygen; here, again, you will, if your experiment be completely carried out, get no putrefaction.

It is not, then, the air proper which produces the decay in the meat.

But ordinary air is by no means air proper; it contains a number of impurities, and the air of all cities always contains a quantity of almost measurable particles of dirt. With this dead dirt we are now almost compelled to believe that small particles of living matter are associated. These small bodies coming into a fluid rich in nutrient matter—as is that with which we have been experimenting—grow up in it and at its expense. To these small bodies it is now the universal custom to attach the name of "Germs."

Before proceeding to a fuller account of the germs and their offspring, we have to direct attention to a general law, which we shall now willingly accept. This law, which has been formulated by one of the most eminent of investigators in this department of knowledge, and, indeed, one of the most eminent of botanists, Prof. Cohn, of Breslau, may be thus definitely stated: "Putrefaction is a concomitant, not of death, but of life." In other words, get rid of your Bacteria and you get rid of decay. Even before this law was stated, the results, gained unconsciously by experience, had been used by many. To these we will shortly return; for the moment it is of greater value to show how the clear understanding and the logical following out of scientific experiments may lead to results of the very highest value to the human race. The experience gained has led to men making money, and to the cheapening of food; the scientific deduction has led to what is for some among us the highest object of their aspirations—the lessening of human suffering.

It is, unfortunately, a matter of common enough knowledge, that after a surgical operation the wound remains sore, and abscesses are very apt to appear. Where a number of patients are gathered together, as in the wards of a hospital, the sores and abscesses are often very considerable. Furthermore, the worse the air, the more frequent the sores. In the country hospital, these *sequelæ* of surgical operations are less virulent and less frequent. Now it is obvious that for all practical purposes, at any rate, the tissues of an open wound are on the very verge, as it were, of death. There may be dead tissue round about, still connected with the rest of the body, but yet shut off from the influences of the blood-supply. With this consideration, we have to associate the fact that the more impure the air, the more frequent the after sore; and, further, we have learned that in ordinary cases of impurity in the air the number of Bacteria germs therein floating is greater than in purer country air.

It was a series of considerations of this character which led Prof. Sir Joseph Lister to the adoption of a systematic attack on the Bacteria. Other surgeons had unconsciously done a good deal to counteract the effects of the floating germs; but to Lister it was reserved to place the treatment to be followed on the definite basis of scientific facts, and the logical deduction of operative principles. This mode of attack, which in this country is known as "the antiseptic treatment," and in Germany, where it has been universally adopted, as "Listerismus," consists essentially in treating the Bacteria with a spray of carbolic acid: the wound and all the instruments and dressings which shall touch it are brought under the influence of this powerful poison. The results obtained by the complete following of Lister's treatment put the question of the influence of Bacteria on dying parts, beyond the range of criticism. More than that, it is reported to diminish the pain, as well as the length of the time during which the patient has to remain under the care of his surgeon.

The history of this discovery and treatment has been, of set purpose, very briefly treated; to have done so more fully would have been to depart from the aim of these pages. Still, enough has been said to direct our minds to this important fact, that blind trials to overcome nature, such trials as those of the earlier surgeons, are less likely to succeed than those which start from a definite series of observed facts, and have their direction impressed on them by general conclusions drawn from these facts. To overcome Nature, we must first get at her secrets — play the Delilah to her Samson.

If we turn from man to the domesticated animals that live with him, we shall again see what value scientific research into these problems has for the agriculturist, and, indeed, for society in general. Sheep and oxen, in various parts of Europe, are at times infected by a disease which is known shortly as "anthrax," or as "splenic fever." Without going into any account of the effects of this fatal disease on the organs of the animal infected, we can measure its results to the farmer by an appeal to statistics. In one small Prussian district £9,000 was lost by the death of sheep from this disease; in three years, the district of

Novgorod, in Russia, lost 56,000 horses and cattle, and 528 human beings.

It has been difficult to know how to combat this terrible plague, the sole cause of which is the little *Bacillus* (Fig. 2). One observer, Dr. Koch, could think of nothing less radical than the utter destruction of all bodies which contain the germs of this peculiar Bacterian form, and what means have been taken to prevent it have been costly and difficult.

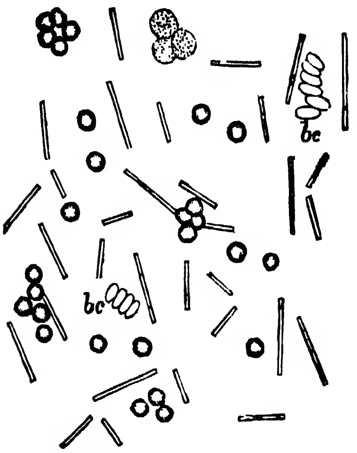

Fig. 2.—*Bacillus anthracis.* (After Koch.) *bc*, Blood corpuscles.

The observer just mentioned, Dr. Koch, has done much to investigate the life history of this form, and this we must know before we can fully comprehend the real bearing of what will follow.

If a small quantity of fluid containing these Bacilli be injected into the system of, say a mouse, the spleen will become enormously swollen, and will be found to contain a number of crystalline rods (Fig. 2). Now, if the mouse be killed, the rods will be found to grow and to divide, and within the rods small bright granules will be found to develope. These are the spores of *Bacillus* (Fig. 3). Under suitable conditions of nourishment, the spores elongate and gradually develope into rods. The dangerous character of the spores will be imagined from the fact that they have been found to retain their fatal influence for at least four years, while the elongated fibres die down within a few weeks. To quote the words in which the present writer put Dr. Koch's account of the matter: "It is a subject for congratulation that Koch has so distinctly shown that the fibres, as compared with the spores, are harmless. Let these remain dry for years, in decomposing fluids for months, be repeatedly dried and as often wetted, still do the spores retain their baneful influence on living animal fluids. A wound, however slight, is sufficiently large to allow them to enter. Use cotton wool to soothe a burn, and, perhaps, you are applying to yourself the seeds of the disease that will kill you; bathe in a stream in which they are resting, and a scratch will offer them a way into your system."*

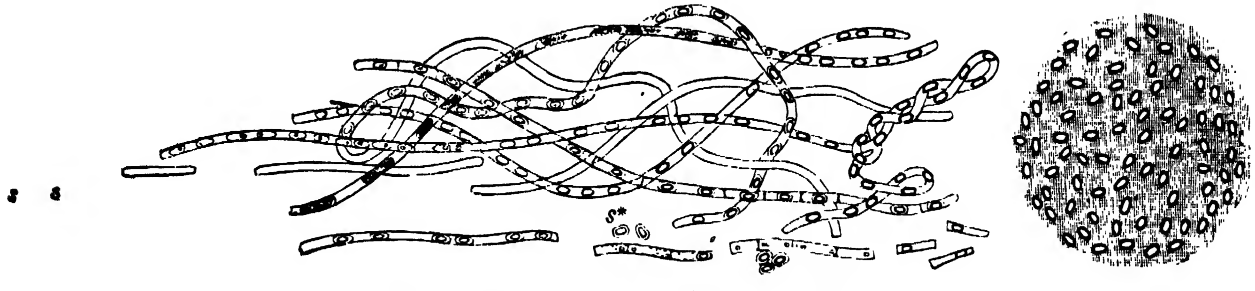

Fig. 3.—Spore Formation in *Bacillus.* (*After Ewart.*)
s, Spores germinating; *s**, Escaped from the rods.

This, then, being the history of these forms, it is easy to imagine that many earnest investigators have directed their attention to its more complete study, and especially to some discovery of the means of prevention. Within the year 1880 the efforts made by the illustrious French naturalist Pasteur, and by M. Toussaint of Toulouse, have been crowned with a measure of success. They have both used what is technically known as the method of inoculation, and, as we know, the process of vaccination, as carried on for ourselves, belongs to this kind of treatment. One of the series of experiments performed by M. Toussaint was of the following character, and it will serve us as a sample of the rest. Blood was taken from a dying sheep, mixed with water, and then passed through a number of sheets of ordinary filtering paper; now, as it happens, the *Bacillus* of anthrax is much larger than the common *Bacterium termo*; it is large enough, at any rate, to be held back by the meshes of the paper; so that all that passes through the filter is a solution of blood *which has been subjected to the action of the Bacillus.* If now a quantity of this blood, which we may justly assume to have been altered in character, since the *Bacillus* lived in it and at its expense, be injected into a blood-vessel of a healthy sheep it will have what we may (for present convenience) call a vaccinating influence. In other words, after twelve or fifteen days the "inoculated" sheep will be found to be secure against anthrax-poisoning, and may be inoculated with it without danger; just as we may be subjected without danger to the contagion of small-pox, after we have been successfully vaccinated.

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* "Quarterly Journal of Microscopic Science," Vol. XVII., p. 91.

Thoughtful minds in all ages have been attracted by the question which they have put to themselves: Whence do these things come? It is not an idle question, although it is often impossible to answer. It is an example of that ardent desire *rerum cognoscere causas*, which is the very fount of all scientific knowledge. Naturally enough men have pondered over these minute germs again and again; and many whose names are held in honour have believed that the germs with which we have been dealing have arisen, unlike other living matter, from dead and not from living substance. This theory, again and again revived, has just as often been successfully combated; but the opponents having worsted the foe have, after all, retired from the field without settling the final question at issue.

So general is the modern belief in the causal relation of germs to disease, that we often find the germs or microbes accused of doing what, at any rate, they have not been proved to do. We should only judge them to be guilty after the most rigorous investigation. The principles on which this should be conducted have been thus laid down by Dr. Koch:—(1) The microbe must be present either in the blood or the diseased tissues of an animal suffering from the disease which it is supposed to have caused; (2) these microbes, removed from their site, must undergo a pure cultivation; (3) such cultivated microbes must be introduced into a healthy animal, susceptible to the disease, and the disease itself must appear; and (4) the microbes must be found in the blood or tissues of the animal subjected to this test. Unless all these conditions are fulfilled we must not assert as a fact that there is any causal relation between a given microbe and a given disease.

There are various methods of obtaining what is called a pure cultivation of a microbe, though all agree in preparing a stock of nutrient material in which the microbes can grow. This stock must, of course, be overheated so as to sterilize it, or destroy any germs that may be present in it. The mixture recommended by Dr. Klein consists of Agar-Agar (Japan isinglass), to which a third of its bulk of peptone solution is added; this mixture should be allowed to become clear before use. The next step is to try and isolate the microbe to be cultivated, and this is effected by one of two methods. When the process of "fractional cultivation" is used, a series of tubes are taken, and successively inoculated one from the other, until at last only one species is found to be growing in a culture tube; when the process of "dilution" is adopted, the culture fluid is largely diluted with a sterile fluid, until at last merely a droplet of the original fluid is taken up by a pipette; here the chances are that you have the germs of a single species only. Owing to the different appearances presented by the colonies of germs as they grow, an investigator is soon able to recognise with the naked eye one kind of microbe from another.

To the diseases which appear to have their cause in the presence of germs there has now for some time been applied the technical epithet of "zymotic;" the root of this word is the Greek for leaven, and the idea which lies at the root of this appellation is that these diseases are to be compared to the well-known process of fermentation. There is, at any rate, very considerable similarity between the two; firstly, there is a morphological resemblance; in the fermentation of beer yeast, the active agent is, as we all know, the simple fungus which is known as the yeast-plant (*Torula*),* in zymotic diseases we have the germs and their products; and secondly, there is a physiological resemblance; in both cases, the effect of the organism ceases after a time; in a given quantity of fluid a certain amount only of fermented matter can be produced, in an "inoculated" organism fresh poison has, for a time at any rate, no poisonous effects.

To the more wholesome and general processes of fermentation, then, let us now turn our attention; and first, let us link it with what has gone before by again relating the activities of a *Bacillus;* this special form is the one which makes its appearance during the process of making cheese; now, as we know, in cheese, just as in bread, there are spaces or cavities; these, it is natural to suppose, owe their existence to the formation of gases, but gases are not formed in milk, or any such bodies, unless some chemical change is going on. Now chemical changes owe their existence either to our adding some agents, in the shape of acids or alkalies, which effect some changes in the relation of the bodies experimented on, or, as taking ourselves in our relation to the atmosphere, to the presence of *living* organisms.

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* "Science for All," Vol. I., p. 51, Figs. 1, 2. More correctly, but less commonly, known as *Saccharomyces*.

When we come to investigate the characters of the history of cheese-making, we find that, first of all, the milk coagulates; then the coagulated *casein* is mechanically separated from the whey; and then finally gases are given off, and spaces are formed in the casein. This activity has been found to be connected with the presence, in the fermenting mass, of a special form of the *Bacillus* organism.

A similar history would apply, in all its essential particulars, to bread, or to beer, or to wine, or to spirit; and that a knowledge of the minute organisms which are concerned in the matter, is now beginning to be universally regarded by those whose business it is to have a definite acquaintance with the details of these things, cannot be better shown than by a reference to the following advertisement which appeared in the *Times* newspaper on the very day on which these lines were being written: "Brewing pupil required . . . . general use of the microscope taught."

Into all the various processes of fermentation it is no purpose of the present paper to enter, but there is one side of it on which one can hardly dwell too long, and which is full of the most instructive lessons. It is this: the power of living organisms is not always, perhaps never, in proportion to their size. The ancients knew this when they invented the fable of the mouse and the lion, but even their reflective minds would have been astonished if they had become acquainted with the exact information as to the measurements of the beer-yeast, which we owe to Professor Nägeli, of Munich. The cells of this ferment-organism are about $\frac{1}{100}$ millimetre in diameter; the contents of each does not exceed one two-millionth of a cubic millimetre, and their weight is no more than that of a milligramme. When they are dried, 80 per cent. of their substance is found to be water; and so we find that mighty as a few of these Torulæ may show themselves, each dried cell weighs no more than one five-millionth ($\frac{1}{5000000}$) of a milligramme. Even here, however, the wonder does not cease; the Torulæ of beer are giants among their fellows!

We will so far imitate the yeast as to give only a little at a time, and will not, on this occasion, enter into the vexed and difficult questions which are connected with the chemistry of fermentative actions; for the present it is enough to insist that the process, whether induced for our welfare or produced to our loss, owes its essence to the presence of living organisms. Fermentation, like putrefaction, would seem to be associated with life, and not with death.

Let us now deal briefly with some of the less well-known forms which have an especial interest of their own.

Nothing impresses the mind like size. Who that has not seen the Pyramids does not look forward to seeing them; who that has ever read Mark Twain's account of the size of St. Peter's at Rome has not, in imagination, sat breathless in amazement? And yet, after all, when the big number is put below, as in a fraction, our wonder may be just as great. You have a man some six feet high making a building the size of which you cannot "cipher," and you have another man looking through a microscope at a living object that he cannot see unless he has the use of glasses which can magnify five thousand diameters.

Such men are Messrs. Dallinger and Drysdale, who have looked at living spores no more than one four-thousandth of an inch (or $\frac{1}{150}$ mm.) in diameter.* It is possible to imagine how bodies so small as this might easily enough escape many of the effects of boiling, if that boiling were not carried on sufficiently long, and how such escape from boiling might lead to the belief that the monads had arisen "of themselves" in the water. As a matter of fact, the philosophical observers just named found that the spores of these monads could survive a heat of 300° F., even when exposed to it for the space of ten minutes. The best method of boiling is the interrupted; that is, repeated boilings with intervals of cooling.

This extreme minuteness of the size of germs gives rise to two results: the one affects men's bodies, the other their minds. The extreme lightness of the germs allows of their being easily distributed. Their small size and the difficulties which attend the detection of them, have led to the framing of hypotheses concerning them which are rendered at once fatal by the objection that there is no cause assigned for the effect.

Taking first the results of the propagation of minute poisonous germs, and inquiring by what means they can make their way into the body, we find ourselves confronted by the following considerations; and as we have already dealt in quite sufficient detail with the after-results of surgical operations, and so far also with wounds due to other causes, we will now only speak of such processes as can reasonably be supposed to affect a healthy body.

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* For astounding facts it is always well to give trustworthy data. In a lecture at the Royal Institution, the Rev. Mr. Dallinger stated that the small *adults* of a monad examined by him and Dr. Drysdale were $\frac{1}{4000}$ inch in diameter. Now 1 millimetre is equal to ·039 inch, so that $\frac{1}{4000}$ inch, when expressed in terms of 1 mm. gives us 1·39 × 4 or $\frac{1}{156}$ mm.

Germs will settle on our body, on our food, in our drink. So much, at any rate, it is easy enough to see. That, however, they can enter it by the skin is a suggestion which can only be made to be at once put aside; but that they can enter through the lungs is a hint which cannot be so easily disposed of, and Professor Nägeli, at any rate, is strongly of opinion that some germs, at least, are able, when they settle on the thin wall which separates the air in the lungs from the blood which it supplies, to set up on this wall an inflammation, to separate thereby the tissues, and so to enter by that little cleft into the great nutrient current which circulates through the body.

Just as certain, too, is it that the light germs taken in with the fluids that we drink are able, by some means, to make their way into the general system of the body; but to enter into a consideration of such diseases as the fevers, erysipelas, or cancer, by whatever ways these commence to operate on the body, would be a tiresome, if not a painful, task. One example will be sufficient to show wherein lies the essence of the whole matter. If you have some grapes, and leave them exposed to the air, they become dry, unfit for eating, and are thrown away; but if, instead of so leaving the grapes, you, without adding anything to them, break their skins by, for example, treading them as the wine-makers of Italy still do, and then leave them, you will find a very different result. Fermentation will be set up, and the sweet contents of the grape will give rise to carbonic acid gas, and to alcohol. You have added nothing, and yet you got this result; the reason ought not now to be very hard to find. Surely enough, the germs of the plant that flourish in the rich contents of the grape-skin bag, were deposited from the air on the skin; they could not reach the juice till the skin was broken, but when that had been artificially done, the germs and the juice came together, and the result, long ago known to mankind, of the formation of fresh bodies was brought about. It will be unnecessary to point out how, by somewhat similar processes, a living organism may be made the prey of the chemical changes brought about by other organisms living at its expense.

To fix in the mind the general conditions of the formation of alcohol by a living body it would be well to perform the following easy but instructive experiment: take a not large test-tube, and fit it with a tight cork; through the cork pass a narrow glass tube, long enough to reach to the bottom of the test-tube; fill this last with a solution of grape sugar, and mix with it a little yeast. Subject this tube to a heat of 100° F. or 38° C. and you will find that a gas is given off; this gas, if collected, may by the ordinary chemical tests be shown to be carbonic acid (as by the milkiness that is produced, when it is shaken up with lime-water), while the fluid that is driven out by the gas may be shown to be alcohol, by the green colour that it will give, if it is boiled with a small quantity of bichromate of potassium and sulphuric acid.

In this experiment we add the organism in the shape of the yeast; in other conditions, nature, fortunately or unfortunately does it for us, but in either case the process and the results are essentially the same.

Here, then, we are brought to just the same conclusion with regard to fermentation, as that to which Professor Cohn brought us with regard to putrefaction. In both cases we require the presence of living organised matter; but, as we have before remarked (p. 90), fermentation may otherwise occur, owing, that is, to the presence of what we spoke of as being *non-morphological* (or not organised) ferments. And herein there lies an essential difference between the two processes; it is rather on the similarity that we would now insist, because it brings us to the other point to which we have just referred.

When it was said that an explanation of what has been observed had been offered by some, which had the fatal objection of not offering sufficient cause for the effects produced, reference was of course made to the doctrine which even now has some vogue, and which teaches that living matter has arisen independently of any pre-existing living matter, or to speak technically, *de novo.*

The objections to the doctrine may be based on two sets of considerations; first of all, in the proved presence of germs in the majority of cases we have a rational and satisfactory explanation; we know these germs may be exceedingly minute, we know that in some bodies the germs may be so hidden away, as it were, as to be able to escape the effects of anything but greatly prolonged boiling, and we know, too, that when solutions are more or less acid the effects of boiling are only sooner or later fatal to the germs. So that, not only have we germs often present, but we have often germs lurking in such a way as to be with difficulty detected. In the second place, the question arises how many of the experiments of any given worker who takes the view now being combated have been in their essence confirmed by others, and how many have been shown to be fallacious. There are but few that have been confirmed, there are many that have been shown to have been imperfectly accomplished, or made under conditions which have deprived the results of any real value.

Putting, then, aside this belief that, in the present, life arises from anything else than pre-existing living matter, we find ourselves face to face with one of the grandest results of later times. The bread we eat, the wine we drink, the disease that weakens or kills us, the hospital fever which retards our recovery, are like ourselves, and like all animals and plants, "Life's children." Go where we will, do what we may, the powers of life are not only working within us but around us, shaping the fates of men, and the fortunes of nations, and yet working always under just the same laws, obeying just the same principles, and causing always much the same effects; breaking up tissues and compounds, using up formed matter, dependent on other matter, owing always their existence to destruction elsewhere.

Beautiful as life is represented to be, such is what life really is; for man it remains, and for man it is a privilege, to order the course of many of its processes. And among these, there is none with which he ought more firmly to battle, none that he ought to learn to conquer, more than these "Germs" which, while they serve him when he makes them aid his will by assisting him in his arts and industries, do by their allies bring on him and on his food, so many of the woes that flesh is heir to.

THE CHEESE-GROTTO OF BERTRICH-BADEN.

By Professor T. G. Bonney, D.Sc., F.R.S., F.G.S.

NOT so very long ago, in a geological sense, volcanoes were abundant in the north-western part of Europe. They vomited forth great sheets of basalt along the western margin of Scotland, they crowned the granite plateau of Auvergne, and they studded the triangular tract of land between the Rhine and the Lower Moselle. In this last district, called the Eifel, no great cones appear to have been piled up; but here and there a wide circular orifice—a crater lake—has been opened, a small volcanic cone been built up, or a stream of lava, generally of no great magnitude, has been ejected.

Near to the southern margin of this district is the village of Bertrich-Baden—a bathing establishment, as its name implies, called into existence by some warm springs which issue at the junction of the igneous and sedimentary rocks: the last signs of the volcanic fires by which the whole neighbourhood has been disturbed. They have been of repute since, at least, the days of the Romans, and are beneficial in cases of gout, rheumatism, and nervous disorders. Sulphate of soda is their principal constituent. Near at hand, on the wooded height, the Falkenlei, a crater of scoria still remains, but the little river Alf has cut deep into the lava stream which overflowed down its valley, and affords us natural sections of much interest. The bottom rock of the country consists of slaty beds belonging to the Devonian series, and must have been fashioned by subaërial forces into something like its present contour before the volcanic epoch began. The upper part is an upland plateau, dotted here and there with copses, but generally a little bare; the glens are thickly wooded and rather pretty. In a tributary glen of the Alf we find the grotto whose name heads this paper. The stream has cut a narrow ravine in the basalt. On its right bank is a projecting mass of this rock. The lower portion, up to the level of a kind of ledge (perhaps partly artificial, as the path runs along it), is only rudely columnar. Then comes a second mass distinctly columnar, capped by a third which only shows traces of columns. The columns in this middle part are at once seen to be not in one piece but very obviously cross-jointed, and on approaching a little nearer are found to be built up of rather flattened spheroids, just like a number of Dutch cheeses. The headland is pierced by a natural passage a few feet wide, and of the same height as the columns, by means of which we obtain an excellent view of the singular structure, from which it has received the name of the "Cheese-grotto." (Fig. 1.)

Two questions will at once suggest themselves to the mind:—How was the grotto made? and what is the explanation of the cheese-like structure of its columns? The former admits of an easy answer. The glen is evidently the result of water-action; the little stream that still ripples down the dark rocks has, in the lapse of ages, sawn its way down through the several parts of the lava-flow. After it had cut through the more solid upper mass, the whole, or a portion of the water, aided probably by the disjointed condition of the next layer, found its way among the "cheeses" at a place where, perhaps, they happened to be rather less tightly packed than usual, and thus began to drill out this grotto. Meanwhile another branch of the stream may have gone on deepening the main ravine. When the grotto had been carried down to the floor—the more solid rock—it must have been deserted by the water, which then confined itself to its ancient course, either owing to the more favourable condition of the subjacent rock, or possibly in consequence of some earthquake dislocation—for such there may well have been—which rendered this the easier path.

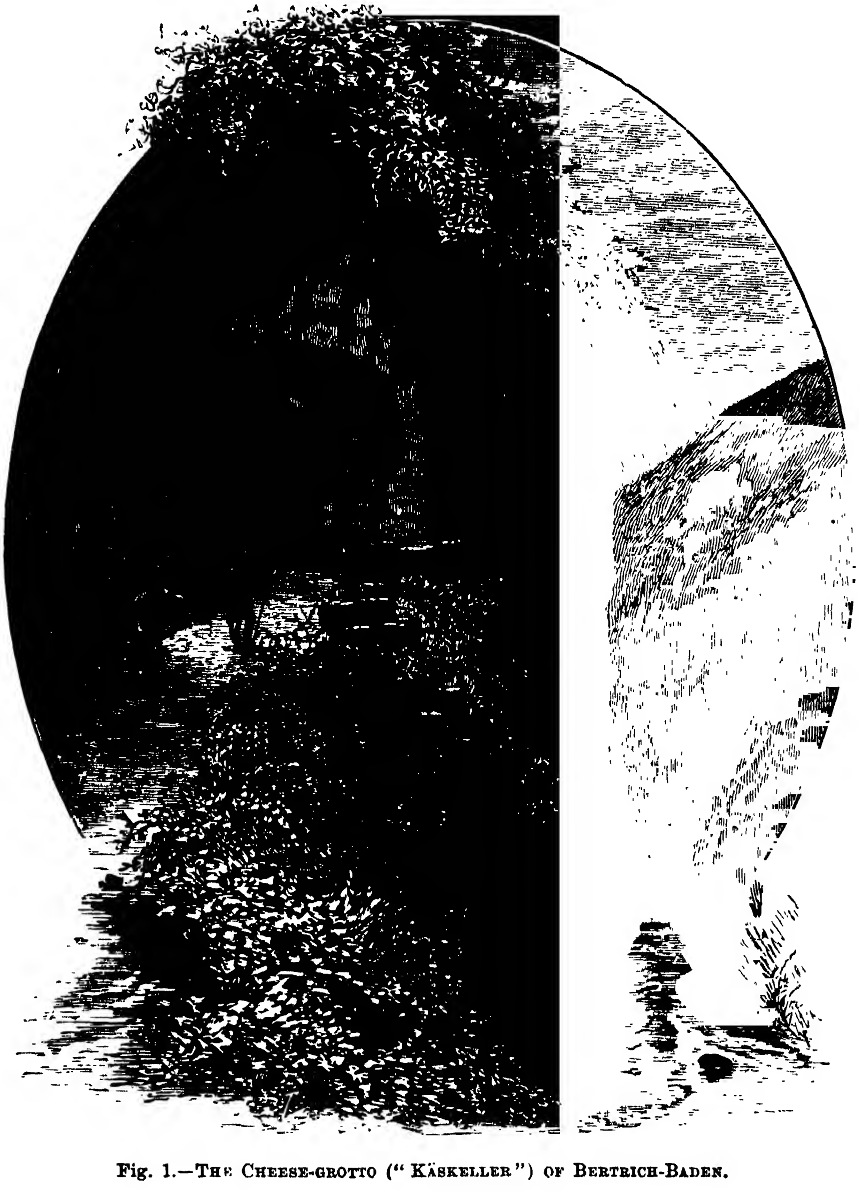

Fig. 1.—The Cheese-grotto ("Käskeller") of Bertrich-Baden.

We have spoken of three masses of lava—and such, so far as structure is concerned, they appear to be—but there is no reason to suppose that in reality there is more than a single stream, in which, as is usually the case, one part only has assumed a perfectly columnar structure, and this has been separated from the others by rather abrupt lines of demarcation.

We come, then, to the cheese-like or spheroidal structure of the columns. Though the Bertrich grotto affords us an admirable example of this, we must not suppose it unique. Spheroidal structure is by no means uncommon in basalt. Sometimes the columns, when decomposition sets in, break up, as they do here, into rounded masses; sometimes the whole mass seems to be composed of irregular balls, not obviously connected with pre-existing columns, and of variable size; and not seldom, when an ordinary cuboidal block is weathering away, it is found to exfoliate in nearly spherical concentric shells. Even where the shafts of the columns show but little tendency to break into these rounded blocks, the ends at the cross joints exhibit what is termed a ball-and-socket structure. Sometimes the whole surface of the joint is curved like the outline of a watch-glass; sometimes it is continued as a plane for a short distance inwards, and the rounded prominence occupies the middle, like those flattened domes upon the tops of houses so conspicuous in views of Eastern cities. The convexities of these curved surfaces do not seem to follow any fixed law; they point sometimes upwards, sometimes downwards, and occasionally may be seen to lie in opposite directions in two columns which are side by side in the same mass. The structure, also, though common in, is not restricted to, basalt. It may be seen in other igneous rocks—as, for example, in trachyte, pitchstone, and obsidian—and sometimes in volcanic ash, as on the Binns, at Burntisland, in Fife (Fig. 2), and at Sta. Lucia, near Caprile, in the Italian Tyrol. It has also been seen in a mass of shale caught up by an igneous rock, in plaster which has dried upon a wall, and in one or two other instances to be referred to presently. It is, then, clear that the cause of the structure must be a general one, not dependent on the particular mineral or chemical condition of the rock.

Various explanations have been offered. Textbooks are commonly in as much confusion about it as they are about columnar structure. Generally it is vaguely referred to as the result of concretionary action—a phrase which is so conveniently hazy that it leaves the matter nearly where it found it. One eminent authority has separated the cup-and-ball structure from the spheroidal, regarding the former as commencing at the centre of the column, and due to a longitudinal tensile stress, which starts often from a small mass of stone different in texture and hardness from the rest of the rock; the latter he regards as not an original concretionary structure, but due to decomposition, penetrating from without inwards, in blocks or fragments into which the rock has been divided by joint planes. We shall see, I think, that there is no reason for this separation, and that the latter part of the theory is quite untenable.

Let us consider this first. No doubt the tendency of the action of the weather upon a cuboidal mass of stone is to round off the angles, as being the parts most exposed to its influence. Then, after a time, it might happen that the parts equally affected by decomposition lay on rudely spheroidal surfaces, and it is possible that the action of penetrating water, under changes of temperature, might produce spheroidal exfoliation. But, leaving possibilities, we have to see whether the facts are in accord with the hypothesis, and this we shall soon find not to be the case.

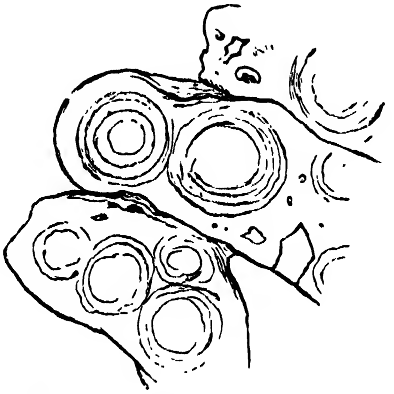

Fig. 2.—Spheroidal Structure in Volcanic Ash (the Binns,

A large number of instances are, no doubt, explicable on this, or on, perhaps, other theories. With these, then, we need not concern ourselves; it will suffice to notice those which are incompatible with it. True spheroidal structure may be seen totally disconnected from external surfaces. For example, a mass of volcanic agglomerates exposed in the steep face of one of the Binns,* exhibits well-marked spheroids (Fig. 2), which, as may be readily seen, are quite independent of the larger bounding surfaces. Again, let us look at the case of spheroids formed in a columnar mass. At the Cheese-grotto, no doubt, where each spheroid is limited above and below by a transverse joint surface, and the whole column, so to say, is built up of cheeses, it might be argued with plausibility that the structure was simply due to exfoliation during decomposition, but other cases may be cited where this explanation utterly breaks

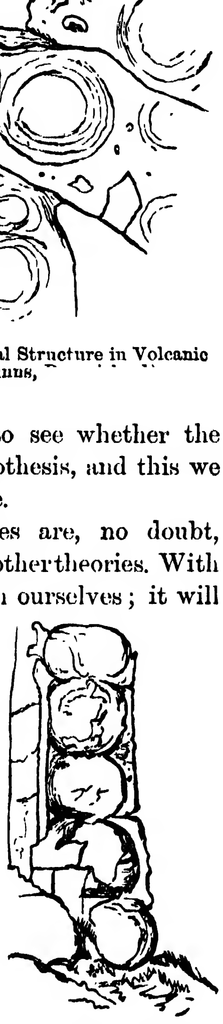

Fig. 3.—Spheroids in an Unjointed Column near Le Puy, Auvergne.

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* "Quarterly Journal of the Geological Society of London," 1876.

down. It requires, we may observe, that the cross joint should be prior to the formation of the spheroid. Now, the annexed figure (Fig. 3) represents a column of basalt seen in the neighbourhood of Le Puy, in Auvergne. The columns had been of the usual form. Some of them still retained this, and externally gave no clue to the existence of a spheroidal structure; but from one or two a part of the surface had scaled off, and exposed a number of spheroids lying within, side by side, like a row of balls packed in a box, or peas in a pod. There were, indeed, some horizontal cracks visible on the sides of the columns, but these appeared quite superficial, and had no correspondence—as may be seen in the diagram—with the bases or any other part of the included spheroids. A similar structure has been observed in trachyte columns, also in Auvergne. Again, if we examine such a structure as is exhibited by Fig. 4—a small part of an old quarry face in the basalt of Rowley Regis—where we see that spheroidal and lenticular masses have formed in blocks of various shapes defined by joints, and that in some of them, within the first formed spheroidal casing, other subspheroidal masses have been produced, so that one nut-shell, as it were, contains two or three kernels—we shall see that it is impossible to explain such a structure as a case of weathering.

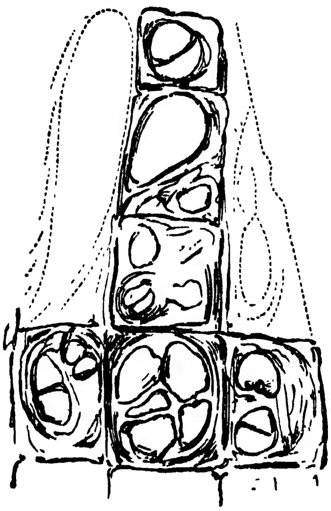

Fig 4.—Complicated Spheroidal Structure (Rowley Regis Basalt.)

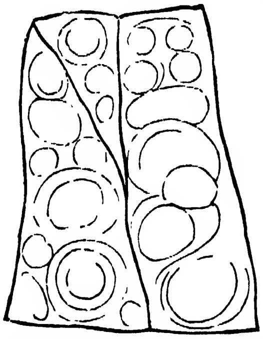

Fig. 5.—Diagram of Perlitic Structure (magnified about six Diameters).

Another instance may be cited which is quite incompatible with that theory. There is a glassy variety of obsidian or pitchstone, called perlite,* which to the eye appears made up of a crowded mass of rounded grains, more or less compressed, which give indication of being formed of concentric shells. They vary in size, but are commonly about an eighth of an inch in diameter. On examining a slice of this glassy rock under the microscope, we see that it exhibits in section a structure (Fig. 5) corresponding with the spheroidal structure described above—that, in short, there is no other difference than that of size; and that the spheroids also may often be seen to occur in groups bounded by minute joint faces. Now, in this case the glassy rock is commonly in a very fresh condition; there are no signs of decomposition, for that would be instantly detected under the microscope. The utmost that can be seen is a very slight staining about the edges of the cracks, which is, at least, just as likely to be the result of subsequent infiltration. The perlitic—that is, the miniature spheroidal structure—cannot, then, be due to decomposition, but must have some other cause; and we may fairly presume that the explanation which serves for the one will apply also to the others, as their only real difference is one of magnitude. We may further observe that this structure is in no way connected with crystallisation, or with anything of that kind. Perlites, when examined microscopically, are seen frequently to contain numbers of small crystals of various minerals; some being like bits of hairs or fragments of the most minute needles, thickly scattered through the mass, and often arranged with a certain parallelism. There are also, sometimes, bands of clearer or of more cloudy glass to be seen. Now, through all these the curved fissures denoting the perlitic structure cut quite indifferently. They have no connection whatever with them, as a rule; they do not seem to be affected by them, and are in all cases subsequent in date.

What explanation, then, can be given? We have seen already† that the hexagonal jointing of the columns was due to the contraction of the mass in the process of cooling. In the formation of these the heat is supposed to be lost uniformly from one of the bounding surfaces, so that a surface, plane or curved, in the mass is reduced to the temperature (whatever it be) at which the particles can no longer mutually re-arrange themselves, but are obliged to ease the strain by rupture. In this case hexagonal cracks are formed; and while this surface of cooling, as it were, subsides into the mass, the hexagonal columns are formed. As cooling proceeds in the mass of each column, now supposed incapable of any more mutual displacement of its particles, strains will again be set up, producing further rupture in the columns themselves. Let us, then, consider the forms which the new fissures will assume. Suppose the loss of heat to take place (we do not say that it does) parallel with the sides of the column, then the surfaces of equal temperature will be respectively parallel with them, the strains will be normal to them, and the fractures corresponding with these surfaces will also be parallel with the sides of the column. Next suppose that the loss of heat continues to be in the same direction as it was when the columns were formed. The surfaces of equal temperature will then be (as before) perpendicular to the axes of the columns; relief from lateral strain has been found, it only remains to ease the vertical; thus cross joints will be formed. Thirdly, suppose that heat is being lost uniformly in all directions in the mass, so that we may assume every part to be nearly at the same temperature, and the strain is no longer to be regarded as acting on a surface but throughout a solid. What form will the cracks then assume? As before, it will be that in which the least resistance is offered to fracture, and the greatest part of the force is effective in producing rupture. But, for any given volume, a sphere is the solid which has the smallest surface area, and thus offers the least resistance, while the whole of the central contractile force is effective in rupturing, because the radii of a sphere are all normal to its surface. Thus a spheroidal structure is the one most easily formed. That the spheroids generally are not true spheres may be due to irregularities in the mode of cooling, or to further compression after they are formed, the mass being still more or less pasty. In the case, then, of the Bertrich "cheeses," the columns were probably first severed by cross joints, and the spheroids then formed in each block as it went on losing heat rather more uniformly. In other cases spheroids may have been formed in the mass without cross jointing, and even without columnar structure being set up; but we regard each spheroid, whether on a large scale or on a small, as a record of the mass having been, at the time of formation, at a uniform temperature, and in a uniform state of strain. The curved watch-glass-like joints indicate that the surface of equal temperature was correspondingly curved at the moment of rupture. This result might be due either to partial loss of heat from the sides of the columns, along the newly-opened fissures, as well as from the ends, or from the dimpling—if one may be permitted the phrase—of the plane surface of equal temperature by the more rapid loss of heat at certain points of the exterior, to which cause also (as explained in the paper already mentioned) the curved tabular joints in certain lavas are due. The ball-and-socket jointing, which appears to be the rarest form, may result either from the simultaneous formation of a horizontal crack at the edge of a column, and a spheroidal crack in the inmost part, which respectively proceed inwards and outwards till they meet; or from the formation of a spheroidal crack in the inner part of the column, which proceeds outwards till it approaches the cooler and harder (but at present unruptured) surface, which, being now reduced to a mere shell, yields to the increasing strain by simply snapping across.

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* A similar structure has been produced artificially in more than one way.

† "A Piece of Whinstone:" "Science for All," Vol. III., pp. 72-5.

Thus all these structures—spheroidal, perlitic, and the various curved forms of jointing—are the results of the same cause which has produced the columnar structure, namely, contraction in the process of cooling—a physical process that in one form or another has played an important part in the earth's history.

RIGHT-HANDEDNESS.

By James Shaw.

ALTHOUGH, at first sight, the four-handed mammals might appear to have a superior organisation to man, yet, because locomotion and prehension have both to be accomplished by the limbs of the former, whereas in man there is a division of labour with his limbs, the upper pair being almost entirely prehensile, the result is that man's two hands are worth more than the ape's four. In extreme youth there is little appreciable difference between the functions of the hands and feet, which alike shove and twist awkwardly in the nurse's arms. At a later period both hands and feet assist in locomotion. It is not until a child has acquired the power of language that the difference between the right hand and left becomes discernible. Nor does this difference quite come of itself, like the difference of voice; or like the beard, announcing puberty, but it is guided into distinctness by precept and example. Around the youthful pupil stand parents, nurse, preceptor, all anxious that he should leave off the use of the "wrong hand," either in labour, or as a matter of courtesy. So persistent and universal is this education that some authorities have deemed the whole difference between right and left hand an affair of fashion; and that if both hands were educated alike it would be a great gain, since in case of any casualty which should deprive a man of the use of the highly-favoured limb, the tedious operation of educating the left hand to do the right hand's work would be avoided.

Nevertheless, if right-handedness be a fashion, it is all but universal, and the most ancient fashion we know. The history of writing, the evidence of language, and the drawings and tools, not only of Egyptians, Assyrians, Greeks, and Romans, but of races, the memory of whose existence had passed away ere the earliest extant records had been penned, and whose rude tools, and weapons, and artistic representations have been disinterred from caves, kitchen-middens, and crannogs, give us early evidence of right-handedness. These drawings represent faces in profile, looking towards the left, just as a street Arab, unless he be left-handed, chalks them on any unoccupied surface. Such is a sketch of the mammoth, on a piece of ivory, found in the rock-shelter at La Madeleine, in the Dordogne. So, also, is the reindeer, etched with great spirit and skill on bones procured from a cave near Bruniquel. Another drawing, in which an eel, two horses' heads, and what Dr. E. B. Tylor has pronounced as possibly the earliest known portrait of man, represents the implement held in the right hand. Professor Daniel Wilson has given three engravings of bronze sickles from the lake of Brienne, all constructed for right-handed men of the Bronze Period. One such handle, found in 1872, was the first example of a complete hafted instrument; and, as Dr. Wilson remarks, is carefully fashioned, so as to adapt it to the grasp of a very small hand, and as incapable of use by a left-handed shearer as a mower's scythe.

In drawing or copying a print, especially if the ornament be of a small and repeating character, we begin at the top of our sheet or tablet on the left-hand side. The reason for so doing is that our hand may not rub upon what is already finished, but not quite dry. This reason seems to have determined the method of writing, which is from left to right. Nevertheless, the most ancient Egyptian writing is like that of a left-handed race, and proceeded from right to left. The figures of men and animals in their hieroglyphics do not shed light on the problem of which was the favourite hand; but their ancient drawings and sculptures are evidence of right-hand superiority. The universality of the preference given to the right hand is as striking as its antiquity. It was wont to be believed that kissing was a sign of affection known all the world over; but our anthropologists have rudely dissipated this pleasant dream, by showing that there are races so benighted as never to have heard of it. Not so with right-handedness. The Eskimo, American Indians, Maoris, Negroes, and natives of the Oceanic Isles place the sword, staff, or whip in the right hand; the shield or reins in the left. The arrow is guided to its mark, the assegai thrown at the enemy, the boomerang aimed at the bird, by the same hand, as a rule, in whatever regions these missiles are employed.

All languages lift up their testimony in favour of the antiquity and universality of right hand preference. Our words "sinister" and "dextrous" are from the Latin for left and right, and our Anglo-Saxon word left, expresses, according to Trench, the little-used hand, being left out of work so frequently compared to its neighbour. *Gauche*, the French word for "left," is, says Brachet, "literally the weak hand which has not the qualities of strength, agility, address, compared to the other. Strange as this may seem," he continues, "it is confirmed by the existence of analogous metaphors in other languages. Thus in Italian the left hand is *stanca*, the fatigued; or *manca*, the defective. Modern Provençal calls it *man seneco*, the decrepit hand." The exceptions to the honour given to the right hand are few, and some of them such as seem to strengthen the rule. Lucky omens were seen to the right of the Roman armies; but, inasmuch as these omens would be considered unlucky from the barbarian's point of view, there might grow up a prejudice against right hand initiative among the latter. There is a widespread feeling that it is uncanny to turn against the sun: we deal out our playing cards in an awkward cross-hand fashion. In the Halloween superstitions of the Scottish peasantry, luck was secured by dipping the left arm or looking over the left shoulder. The falcon, save in Asia, is held on the wrist of the left hand. With the Chinese the place of honour is towards the left. And when Commander Cameron crossed Africa, he was surprised to see at Kanyanyé, the heir-presumptive to a "throne" with the nails of his left hand grown to an enormous length, as a sign of high rank. The hand, owing to disuse, was much smaller than its fellow.

As man rises from a state of barbarism to that of civilisation, the education of the right hand becomes more urgent. A hunter of wild beasts, or a cattle-drover losing a right arm, would not sustain so serious a misfortune as if the same loss occurred to an engraver or clerk in modern times. We can easily imagine that the transfer of a spear or stick to the other hand would be less irksome than the many trials to write well with the left. As men began to unite in bodies, requiring simultaneous combined movements, the pre-historic drill-sergeants would not be slow to discover the advantage of troops covering the heart with the shield by the hand that lay nearest it, and having the sword-hand free throughout the whole line, ready for offence. As tools became more numerous, varied, and complex, it would be a matter of importance to make them to suit one hand rather than the other; and so now we find that a left-handed man is handicapped, since many of our most useful tools, &c., the screw, the gimlet, scissors, carpenters' benches, printcutters' gauges, and even that latest novelty, the "moustache cup," are all made for a world of right-handed men. This tendency to specialisation may be seen in clothes, the buttons being placed on one side, the loopholes on another. Gloves adapted for each hand, and shoes for either foot, are luxuries which have reached the poorer classes at a comparatively recent date. In the struggle for supremacy, left-handed persons are, amongst us, like foreigners speaking no other language but their own, and from their want of fitness are apt to fall behind. The duty of giving preference to the right hand seems more imperiously enjoined in families whose education and social position are most advanced; and it has been remarked that the number of ambidexter, or left-handed individuals is proportionally larger as we descend the scale, being greatest in such localities as the Fiji Islands and places remote from civilisation.

Is all such anxiety to educate the right hand exclusively not somewhat misdirected? Would it not be an advantage to have each hand equally deft? There appears to be no inherent deficiency in the left hand of the violinist, or of the charioteer, for the hand that regulates the delicate chords of the violin or the reins of the spirited steed takes upon itself more responsibility than the one which guides the bow or the whip. Eminent painters, surgeons, musicians, athletes, have been enumerated who were either left-handed or ambidexter. Why should not hands be trained like eyes, giving a free field and no favour to either? Then should the king meet with accident, there would be a prince equally accomplished to take his place. Perhaps it is too late to expect for this question the answer which one, prepossessed in favour of an ambidextrous education, would desire. The antiquity and universality of the preference are enough to cause suspicion that it has now got into the blood, and is not likely to be easily eradicated.

Various theories have been set forward to account for this peculiarity of the sons of Adam. Aristotle seems to have been the first to display philosophical curiosity on the subject. He tells us that there is a right and a left in animals, which different sides must be determined, not by position, but by function. He goes on, in his own way, to give a reason for right hand predominance, and why it is that burdens should be carried on the left shoulder. In a memoir, published by Professor Buchanan, of Glasgow, the preference of the right hand, as well as the equally old and prevalent custom, attested by the most ancient monuments, of carrying burdens on the left shoulder, was alleged to be due to the want of symmetry in the human body. The centre of gravity, it was argued, was not in the medial line, but inclined towards the right, the right lung being larger than the left; and the liver, the heaviest of the internal organs, occupying a place towards the right. Owing to this cause a mechanical reason was given for the right arm acting with greater power; while it was argued that in carrying a burden on the left shoulder, the porter stooped forward towards the right, thus bringing the weight to be upheld more directly above the stronger right limb. The weakest part of the argument was that which required transposition of the viscera to account for left-handedness.

Transposition of the viscera is extremely rare, but left-handedness is a phenomenon with which everybody is acquainted; it is accompanied by the same larger-sized left limbs that are so normally, in the right, and can be shown to run in families. Indeed, in at least one case of transposition of the viscera the subject was right-handed. Anatomists, who have made additional observations, confirm Dr. Buchanan's remarks on the relatively greater weight of the right side in adults, and consequently of the position of the centre of gravity being towards that side, although pointing out that in children and quadrupeds the body is more symmetrical.

Another theory is founded on the fact of the brain being composed of two hemispheres, which work the muscles cross-wise, so that disease or weakness of a hemisphere affects the whole opposite side of the body. Gratiolet had observed that the right side was worked with more nervous energy, since, even at an early date, the anterior, and middle lobes of the brain in the left side were more largely developed; and the late M. Paul Broca records that in forty brains which he had examined, he found the left frontal lobe heavier than the right. Further independent observations are needed to confirm the theory of right-handedness depending on the greater energy supplied to the right side by the larger left hemisphere.

Nature, when there is a purpose to serve, is nowise loth to depart from symmetrical form. This may be observed in our crustaceans, especially the hermit crab of our coasts, which has one set of limbs, notably those in front, which protrude from the shell longer than the set on the other side. The tusks of the narwhal are very unequally developed. In serpents the lung most developed is the right. In birds the aborted ovary and oviduct are the right. The sole's eyes are twisted to the right, the turbot's to the left. Parrots perch and feed with a preferential claw. Training induces preference, as in the case of the dog which "gives paw" with the limb so trained, and the horse which leads with the right foot in a canter. The African elephant uses one of its tusks more frequently than the other for digging roots, &c. This tusk, from being often broken, is called the "servant" by the ivory traders, and is of less value. It is most frequently the right. In the two eyes of many persons the focus is different, the right eye being the one generally, it is thought, with stronger vision. The curious circumstance of travellers, bewildered on a prairie, or amid mists, striking their own footmarks after completing a circle, has been referred to the agility and strength of the right limb unconsciously pulling slightly in advance. Catlin says that the Indians all assured him that the wanderer invariably turns to the left, a fact of which he became fully convinced by subsequent proofs.

COHESION FIGURES.

By William Ackroyd, F.I.C.

WHATEVER an "atom" may be—and its nature will be discussed on another occasion—it is certain that if one could question it properly as to its past history, it would reveal to us extraordinary facts about its imprisonments and its journeyings. How, for example, after being locked up in the bowels of the earth for ages, it was liberated in the course of some sudden commotion, and then, flitting hither and thither in company with a fellow atom, it was now in the primeval forests of the far West, then among the ice mountains of the far North, or again wandering about the burning tropics; or it might be that it was an integral part of some monster which was wont to prowl about the carboniferous jungles: and now, after untold cycles of change, it has become as certain a part of some fair lady's finger. All this is very probable, and not a whit more extraordinary than what Shakspere's common sense told him respecting the "noble dust" of Alexander.

In following the fortunes of some individual atom, say one of oxygen, we should be told that it had often had strange mates, for it would speak of its having been occasionally linked with a couple of hydrogen atoms (or as the chemist states the fact by the symbol OH_2), and travelling in their company either as part of the ocean current or of the iceberg; of its having been joined to a single carbon atom (CO) to form part of a quantity of that poisonous gas which chemists call carbonic oxide, and in this company it may have played a prominent part in some mysterious human tragedy; and of its having been joined at another time to an oxygen atom as well as a carbon atom, to form carbonic acid (CO_2) and so it remained until it was liberated by the magic influence of a sunbeam. No matter, however, with what atom or atoms it was linked, they were all held together by a mysterious force to which the name of *chemical attraction* has been given, and such an atom-cluster is generally known as a molecule. Now, although it is with molecules that we have to deal, we know very little about their individual qualities, about their forms, sizes, and so on. They are mysterious things concerning which we speculate, and it is likely that always our views of them will be confined to the mind's eye.

But while we can learn little that is positive about collections of atoms, we know much about collections of molecules. Every solid substance is a vast collection of them held together by a force to which the name of *cohesion* is given, so that it will be seen that cohesion is an attraction which apparently holds an intermediate place between gravity on the one hand, which acts through vast distances of space, and chemical attraction on the other, whose influence is only felt between contiguous atoms. At what distance does cohesion act —in other words, how far must a couple of molecules be forced apart so that they no longer pull at each other? Attempts have been made to answer this question. When a liquid film is stretched we come at last to a point where cohesion will no longer hold its molecules together, and it is evident that the thinner we can get a film of this sort, the more nearly must its thickness be comparable with the distance at which cohesion acts between neighbouring molecules. Rücker and Reinold have made measurements of black soap films of extreme tenuity, and have found their average thickness to be twelve millionths of a millimetre, from which one is warranted in concluding that the distance at which the neighbouring molecules of a soap film attract each other is less than twelve millionths of a millimetre, or less than half a millionth of an inch. Such is the vast difference between cohesion and gravity, our units in the one case being millionths of an inch, in the other, millions of miles! Minute, however, as the distance is at which cohesion comes into play, it is possible to bring two surfaces sufficiently near together for the molecules to pull at each other. Thus if two surfaces of lead are made quite clean and flat by scraping, they will cohere very remarkably if pressed together with a certain amount of force.

On the way to the extreme thinness of film at which it breaks, we are accustomed to seeing the beautiful phenomena of iridescence which are so well displayed in soap bubbles. Some wonderful exhibitions of this kind may be obtained with films of another sort. Allow a drop of oil to fall on the surface of a sheet of still and clean water. It will spread out into a circular thin film. The oil as a drop was globular, in virtue of the cohesion which kept its molecules together; after falling on the water, forces were called into play which are antagonistic to cohesion, so that before many seconds the film became covered with myriads of holes where the film had broken. When rapidly spreading out, lovely concentric rings of colour were seen by an eye suitably placed, and these gradually disappeared as the break-up became general. The film presenting these various appearances is known as a cohesion figure.

"Cohesion figures" have been much studied since Charles Tomlinson, in 1861, introduced them to the notice of the British Association, meeting in that year at Manchester. And it is not one of the least inducements to a study of these figures that all the apparatus and most of the materials are close at hand, even in the humblest dwelling. We require an ordinary dinner-plate, water, oil, and a needle for the production of the figures; and if we want to preserve the pattern—a simple operation giving a very beautiful result—we require further some white paper, a second plate, and a supply of good ink.

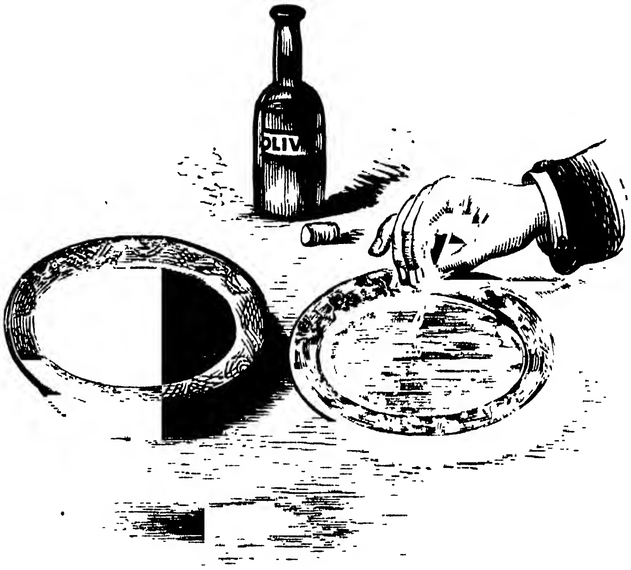
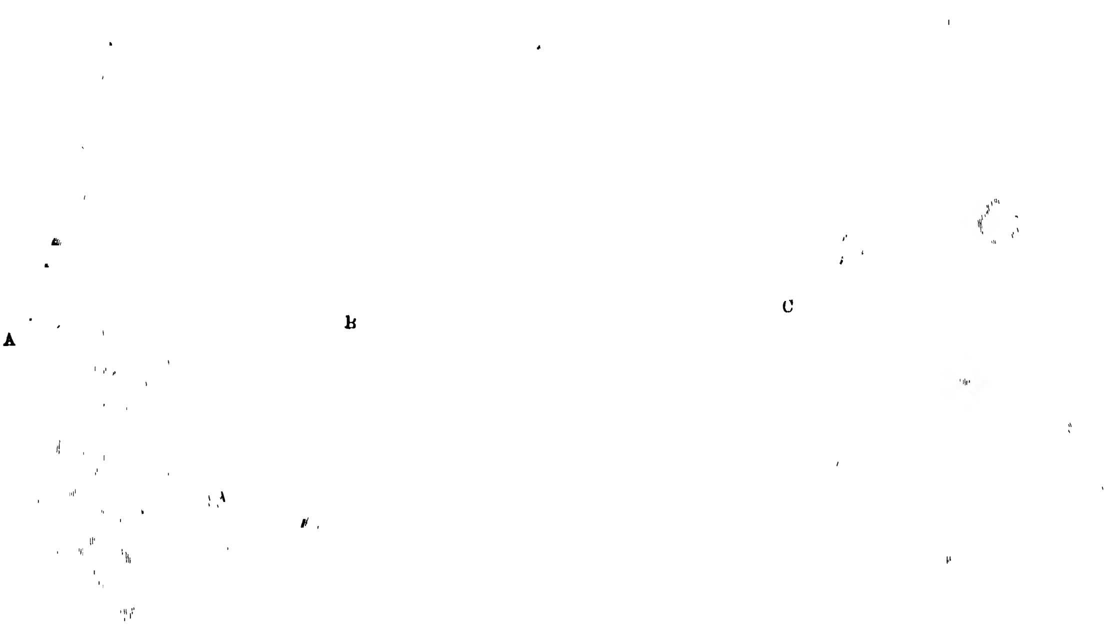


Fig. 1.—Making Cohesion Figures

Let us suppose, then, that all these materials are at hand. The two plates are placed on a table just below the window, so that when they are filled with liquid one can readily see by means of the light reflected from the surface what is going on there. The plates are scrupulously clean, and one is filled with ink and the other with water. Now take a bottle of oil, labelled, say, "finely perfumed hair oil," and dip the needle into it. Drops of oil fall from the point, the first two somewhat quickly and the remainder more leisurely (Fig. 1). The needle point is now held about an inch over the surface of the pure water while a drop is slowly forming; at last it falls, and spreads out on the surface. The globule of oil of a small fraction of an inch in diameter is spread out into a circle of many inches in diameter. This thinning out proceeds at first quickly, and then more slowly, and finally imperceptibly. The oil film becomes so thin that iridescent colours begin to make their appearance, and you may have a beautiful green field in the centre with a border of pink all round it; and perchance when you notice the colour again, a few seconds after, the central field has changed to a rosy hue, while the border has adopted the grassy tint. In the meantime the film has commenced to break up, the circular holes at first formed becoming larger, until they encroach on each other, and the whole pattern appears a network of oil fibres, which finally break up into minute dots or islands of oil. Let us suppose that at this point we proceed to take an oleograph. A circular piece of clean white paper is placed over the oil film and pressed down evenly; the film adheres to the paper. It is now removed and transferred just in the same way to the surface of the ink, and after remaining there say five minutes, it is taken up and washed copiously with clean water. When dry the paper will be seen to have on it a permanent copy of the cohesion figure, very often, however, marred by the clumsiness of the manipulator. This method of copying cohesion figures was devised by Dr. Carter Moffatt. Fig. 2 is a sector cut out of such a copy, or oleograph, which was obtained when the film of hair oil had taken its final form.



3.—Sectors of Cohesion Figures produced with Olive Oil, one (A), one and a half (B), and three (C) minutes after drop falls

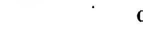


Fig 2.- Sector of a Cohesion Figure.

And now, supposing the reader takes a little olive oil, he will find upon experimenting with it that it behaves differently from some other oil he may have been trying. When he proceeds to take oleographs he will also perceive the difference there. With watch by the side of the plate for noting time, the experimenter will probably get something like the following order of appearances. Thirty seconds after the drop falls, myriads of holes, with centre of circular area green, and border of a rosy tint. In forty-five to sixty seconds the iridescence has vanished, original minute holes having coalesced to form larger ones, which are largest towards the border. In a minute and a half there is a broken network of oil filaments, while at the end of three minutes filaments are no longer to be seen, but simply a number of small oil islands, mostly circular in form, and some of them enclosing minute lakes. It would take up too much space to give copies of the oleographs of their natural size obtained at these various stages, and we therefore represent in Fig. 3 slices of the figures bounded by two radii, and the outer border, a plan which answers exactly the same end. Very much of the beauty of a cohesion figure cannot, however, be reproduced by means of oleographs, especially the iridescence which is seen at early stages of their formation. One might say, indeed, that the figure bears the same relation to the oleograph that a landscape does to a photograph, or a stretch of country to the map of it. In the oleograph we have only a plan; and indications of thickness as presented in the pink and green of an olive oil film, or the glory of an incipient castor oil film are altogether lost.

Some of the figures that may be obtained are very characteristic, so much so as to enable one to tell what kind of oil is being employed, and Tomlinson has even told the difference between oils so closely related as the oleines of beef-fat and mutton-fat. He does not seem, however, to have been in favour of oleography for this purpose after its introduction by Dr. Moffatt, as he expressed the opinion that "the cohesion figures of liquids are in themselves oil tests; but when transferred to paper, the resemblance between the figure of one oil and that of another is so close that they may be taken as identical."

Under the head of cohesion figures some other curious phenomena have been hitherto described, although it is doubtful whether some of them have been properly placed in this respect. Thus in the following experiment, which has been described as a case of "submersion cohesion figure," the reader will readily discern liquid vortex rings.* Fill a tumbler with water, and when quiet dip a pen-point just below the surface. One descending ring of ink will be first seen, which very soon develops into a system of minor rings. It is to be observed, however, that the so-called cases of submersion cohesion figures were studied before vortex motion had received any practical attention at the hands of scientific men. We perhaps might with more justice bring under the head of cohesion figures the very interesting appearances which are known as "Breath Figures." If a piece of window pane be well cleaned, it will be found a few hours after that if one writes anything on it with a brass point and then breathes upon the pane the writing will be quite visible. It is thus explained:—The surfaces of all bodies are supposed to be covered with an invisible layer of condensed air and condensed aqueous vapour. And in passing we may observe that there is nothing very extraordinary in this supposition, as surface condensation of this kind may give rise to the development of heat, which may be made evident in this way. Take a clean piece of platinum wire, wind it into a spiral, and place it in the top of a Bunsen burner. Upon now allowing the mixture of air and gas to pass over it, it will grow red hot, and much hotter still, until it ignites the mixture, this being due to the condensation of the mixed air and gas by the surface of the clean spiral of platinum (Fig. 4).

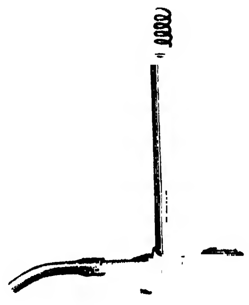
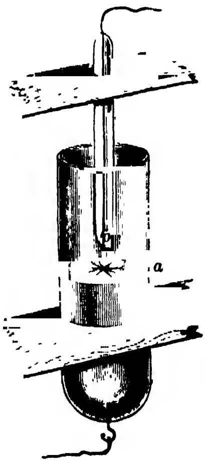


Fig. 4.—Surface Condensation.

To return, then, to the breath figures. When one writes on the glass with a hard point, the condensed air and vapour adhering to the glass are removed from the parts written on. Upon breathing on the plate there is now an unequal deposition of the vapour contained in the breath, the portions of the plate covered with condensed air and those from which it has been removed by writing condensing the vapour unequally, and thus making the writing visible.



of a Liquid.

Another class of appearances which differ very markedly from the preceding has been described as "electric cohesion figures." Such a figure is the ever-varying appearance presented by an induced spark under certain circumstances, as, *e.g.*, when one is passing a spark (Fig. 5) between a surface of liquid, *a*, and a metal point, *p*, for spectroscopic purposes. Under suitable conditions there is seen on the surface of the liquid a figure made up of irregular radiating lines of light. These figures were first described by the late Dr. Strethill Wright in 1863, and the method he adopted for getting them was this. A drop of liquid is laid on a clean sheet of glass or mica, which rests on a blackened plate of metal. One of the poles of a coil is connected with the metal plate, and the other dips into the drop. When the current is passed, the characteristic radiating figure of light is observed of a shape which varies with the nature of the drop; in other words, the figure varies with the cohesion existing between its molecules, and with the amount of adhesion the drop has for the mica or glass plate. In Fig. 6 we have the appearance presented by a spark when mica and a drop of cyanide of potassium solution are used. It is hardly necessary to add that solutions of different kinds give a great variety of figures.

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* "Science for All," Vol. I., p. 43.

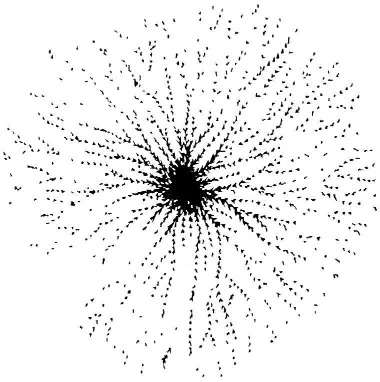


Fig. 6.—An Electric Cohesion Figure.

From what we have said regarding the evanescent forms to which the name of cohesion figures has been applied, it will be seen that their study affords no small amount of pleasure and instruction. It will be, moreover, evident that the appearances most meriting the name are the oil films with which we commenced, for here in the spreading oil circle cohesion is gradually overcome, but again reasserts itself, when the iridescence disappears and minute oil drops are formed once more, so that cohesion is concerned in every phase of the changing figure.

ANIMALS OLD AND NEW.

By Professor P. Martin Duncan, F.R.S.

The great nations of antiquity, whose works of art and literature have descended to modern times, became aware of a very important fact in natural history. They warred with their neighbours, and wandered far and wide over Western and Central Asia, Hindostan, Nilotic Africa, Arabia, and South-Eastern Europe, and their geographers and travellers told of the strange animals which were to be seen remote from home. The fact that the same kinds of animals are not to be found everywhere, was thus a very early discovery. It was rendered all the more valuable and interesting to the first students of natural history, by the gradual progress of the knowledge of the truth that certain countries or parts of the world have animals living in them which are not found elsewhere, and are, as it were, peculiar to them. Nations from Central and Western Asia poured in a stream of conquest into the Indo-Gangetic plains, across the passes of Afghanistan, and saw for the first time huge elephants, the rhinoceros, the tiger, and a wilderness of long-tailed monkeys. But they missed the lion, the camel, the goat, and the wild ass, the familiar natural history objects of their own land. These restless people moved in great armies into Syria, and passing southwards entered, and fought with varying success against the ancient races of North-Eastern Africa. There they beheld, up the Nile, the hippopotamus, the long-necked giraffe, and an elephant differing in its kind from the Asiatic one, besides the crocodile. Their native animals were not seen there, and even the lion differed in its mane. As years rolled on, the Greeks and Romans enlarged upon these simple truths, and the people were shown African and Asiatic animals, and feasted, not with natural history knowledge, but with the sight of the blood and destruction of the gigantic creatures, whose forms and methods of life were utterly unlike those of the familiar wild animals of Europe, such as the wolf, bear, boar, and deer. This knowledge of the ancients laid the foundation of the study of the "distribution of animals," and doubtless many a thoughtful lover of nature speculated why these things should be.

As the world grew older and as knowledge increased, it became evident that the simple truths discovered by the early naturalists were of great importance, for they were not only applicable to those portions of the globe which were known to the ancients, but to the whole of the land of the world. Thus after Columbus discovered the New World, the Spaniards, French, and English began to conquer and colonise North America; and one of the first marvels they witnessed was that the animals were different from those of the Old World. South America offered greater cause for wonder than the northern part of that immense continent, for not only were the animals of its vast forests, and great plains, and high hills, different from those of Europe and Asia, but they differed almost completely from the beasts of North America to the north of Mexico. There were monkeys there, with prehensile tails, sloths hanging, back downwards, from the boughs as they fed, armoured creatures which burrowed, huge gnawers by the river sides, and active long-legged llamas on the southern plains. In after years, Captain Cook landing in the south of Australia, saw the great kangaroo for the first time, and as settler after settler examined the great country, one and all told the same tale that there were no European, Asiatic, or American animals there, but a set of creatures of the kangaroo tribe which led many kinds of lives. The story of this gradual elaboration of a truth is as interesting as the fact itself. And careful investigation, assisted by common knowledge, had during all these years, explained that whilst different parts of the globe were tenanted by different groups of animals, there were some animals which were common to some of the distant countries. Many birds of powerful flight are found very widely distributed, and some animals wander far and wide on continents, especially those which prey upon others. These wanderers have exceptional powers of getting about, of locomotion, and can either fly, swim, or climb well. They are termed "sporadic," from the Greek *sporas*, scattered about. The same kind of study proved that the animals which were peculiar to each great country had not these locomotive powers, and also that their restriction within the limits of certain countries, was due partly to the physical geography. The word country was dropped, as it had a political signification, and each of the so-called countries, which were limited by natural barriers, such as wide seas, table-lands, mountain chains, and deserts, was termed a natural history province, or a distributional province. These barriers restrict the animals without the power of flight, of swimming, or climbing, within their boundaries, so that each natural history province has a fauna — an assemblage of animals—peculiar to it, unlike those of other provinces, and some of the animals are especially characteristic.

The physical geography—that is to say, the present aspect of nature—is thus clearly in relation with the distribution of animals about the world. The limits of the natural history provinces are of a physical kind, and so long as these physical conditions—these barriers—last, so long will the present natural history provinces retain their peculiar and characteristic faunas.

During the progress of the collection of the facts which are the foundation of the theory of the relation of physical geography to the distribution of animals, much knowledge was obtained regarding the past history of the globe. The present aspect of nature was shown to be the outcome of changes which had been modifying the surface of the earth during ages gone by; and it was explained by the geologist that the great land surfaces now recognisable were parts of larger ones which existed during the age before the present. The limiting barriers were of such a nature then, that there were natural history provinces within them. Moreover, in digging canals, clearing out bogs and lakes, and in making the foundations of buildings during the middle ages, huge bones were frequently found deep in gravel and clay, in situations indicating a high antiquity; that is to say, in sediments which had collected before men wrote histories. Bones of the limbs and body, and huge skulls and teeth were found, and were attributed by the ignorant to human giants, and, in one celebrated instance, to a saint. Subsequently, great numbers of bones were found in the gravels upon the flanks of the hills bordering valleys, and also in caves, where they were hidden up under a crust of solid carbonate of lime called stalagmite. The science of comparative anatomy, which investigates the structures of animals, and compares them one with another, and with those of man, arose during these discoveries; and under its auspices the great bones were studied and compared. They were found not to resemble those of men, but those of some living animals. The resemblance in some instances was exact, and in others it was close, but not exact. On the belief in the continuity of the laws of nature, and that there has been a plan and philosophy in the past as there is in the present, it is possible to study the old bones, and to clothe them, in the scientific imagination.

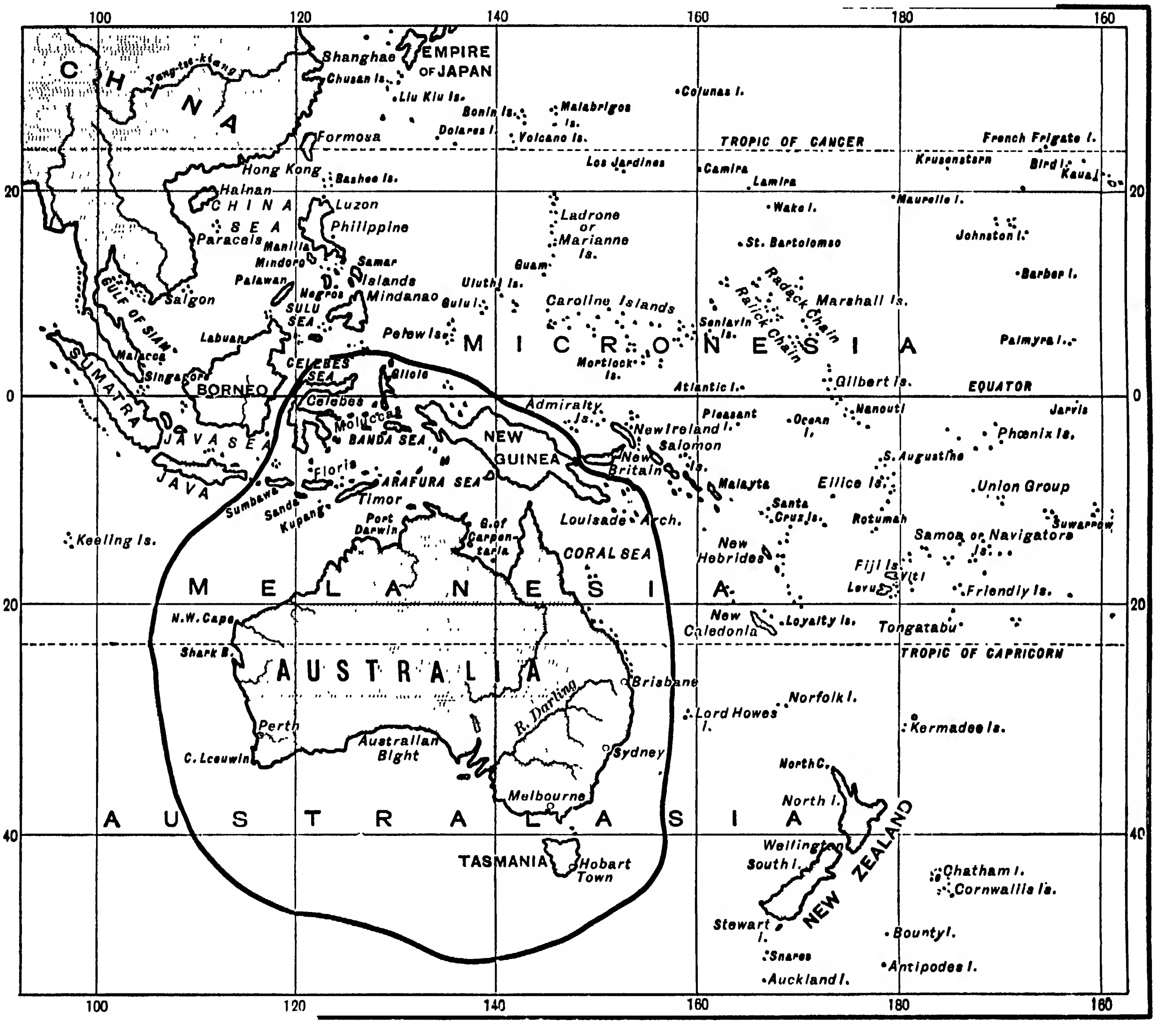
with muscles, flesh, and skin. It is reasonable to affirm that if the bones of one skeleton resemble exactly those of another, never mind what the difference in age may be, or whether one has been found deep in the earth and the other has lately lived, they belong to the same species, and had the same general shape. Again, if the resemblance is not exact, the similarity of the shape of the ancient and modern animal has a clear relation to the amount of anatomical resemblance. The old creatures did not belong to the same species as their nearest resemblers now living, but to the same genus. Finally, if the old bones do not resemble those of any modern genus, but have a general likeness to some great group or family, they are to be included in a new genus of the family.

These rules infer that some of those great bones belonged to animals which resembled some of those now living on the earth, and that others belonged to creatures differing from those now living in species, but which would be included in the same genus or family by the naturalist. In fact, there have been animals on the earth which have become extinct, and others which have lasted on since the last geological age into the present. Thus not only has the present aspect of nature been the outcome of the past, but animated nature was foreshadowed in the past, and has, to a certain extent, descended from it. Take an example or two in order to fix these statements on the memory. A skull with the teeth is found in a cave; it is compared with one of a man, and it does not resemble it, and therefore it belonged to some animal. Next, it is compared with the skulls of several skeletons of different animals, and it is found to resemble exactly that of a hyena from Africa. The fossil skull is then said to have belonged to the species of hyena which still lives, and it proves the great antiquity of the species.

Again, a skull with tusks and some huge limb bones are found, and are compared with those of the skeletons of species of animals which are in the existing creation. The old bones turn out to be not exactly like any others, but to closely resemble those of the elephant. They did not, therefore, belong to any species of elephant which now exists, but to an animal, elephant-like, and of the same "genus." They were bones of the woolly elephant of Siberia, the mammoth—the *Elephas primigenius* of naturalists. This is an extinct animal, and its structure indicates that the elephants of the past were closely connected with those of the present in a creative scheme or philosophy.

Finally, a skull with two great tusks in the lower jaw, curved downwards, was dug up and compared. It was found to be unlike any other, but its nearest resemblance was with that of the elephant. It could not be included in the genus, so great was the distinction, but it might be placed in the great family of the tusk-bearing, thick-skinned animals, with a proboscis, in a genus of its own. It is an extinct animal, and on the whole was elephantish, but belonged to the genus Dinotherium, of the group Pachydermata or Proboscidea, to which the mammoth and elephant belong.

The question naturally rises in the mind, If there were large and small animals living on the globe just before the last great change of its surface which developed the present state of things, were they in natural history provinces, or did they roam universally? The answer is, There were natural history provinces then, and some of them were limited to the same locality as they are now, and others were either larger or smaller; but still their general position was very much the same as it is now. The next question which follows as a matter of course is, Were there peculiar animals characteristic of each natural history province formerly, and what was the relation in size, shape, and kind of those old creatures to those which now characterise their especial districts? In answering these inquiries, it is necessary to examine into several branches of natural history, and to explain minutely some of the more general assertions which have been stated. When this subject of the restriction of vast numbers of animals within countries bounded by certain natural barriers was first carefully considered, Dr. Sclater characterised the different provinces by certain of their birds; by birds which cannot fly or swim. Following his example, consider the locomotive powers of an ostrich. It is a tall, long-legged bird, with long toes which are not webbed; it has a small body, a long neck, and small head, and there are small wings which flap the front and sides of the body. The feathers are not like those of the birds with powerful wings, and in fact, the wings are rudimentary, being so nude that they are of no more use in the attempt to fly than the little wings of a chicken just hatched. There are other kinds of these wingless, long-legged birds, such as the emu, cassowary, and there are South American and African ostriches. Now the ostrich and its fellows can scamper over plains and lowlands, and can jump over many obstacles, but they cannot cross wide rivers and arms of the sea, or climb or pass over high mountains. It is evident that such a bird will be restricted in its roaming by many natural barriers, and that so long as these last, so long will the ostriches remain within them. A long-legged, wingless bird is, therefore, a very characteristic form of living thing in relation to physical geography. If the land of South America ceased to be surrounded by barriers impassable by the ostrich called Rhea, it would get into North America; but it is not found there, and, therefore, it follows that the barrier which separates the north from the south of America is as old as the Rhea and its ancestors.



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CHINA
EMPIRE OF JAPAN
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Liu Kiu Is.
Bonin Is.
Malabrigos Is.
Volcano Is.
Dolores I.
Formosa
Colunas I.
TROPIC OF CANCER
French Frigate I.
Hong Kong
Bashee Is.
Los Jardines
Camira
Lamira
Krusenstern
Bird I.
Kauai
Hainan
CHINA SEA
Paracels
Luzon
Philippine
Manilla
Mindoro
Samar
Islands
Ladrone or Marianne Is.
Wake I.
Maurelle I.
Johnston I.
St. Bartolomeo
Guam
Palawan
Negros
Mindanao
Uluthi Is.
Gului Is.
Caroline Islands
Radack Chain
Ralick Chain
Marshall Is.
Barber I.
Saigon
GULF OF SIAM
SULU SEA
Labuan
Pelew Is.
Senlavin Is.
Palmyra I.
MICRONESIA
Malacca
SUMATRA
Singapore
BORNEO
CELEBES SEA
Gilolo
Mortlock Is.
Atlantic I.
Gilbert Is.
EQUATOR
Celebes
Moluccas
BANDA SEA
Admiralty Is.
New Ireland
Pleasant I.
Ocean I.
Nanouti
Jarvis
Phoenix Is.
JAVA SEA
JAVA
NEW GUINEA
Solomon Is.
New Britain
S. Augustine
Flores
ARAFURA SEA
Timor
Malayta
Santa Cruz Is.
Ellice Is.
Union Group
Sumbawa
Sandal
Kupang
Port Darwin
G. of Carpentaria
Louisade Arch.
Rotumah
Samoa or Navigators Is.
Suwarrow
Keeling Is.
CORAL SEA
New Hebrides
Fiji Is.
Viti
Levu
MELANESIA
Friendly Is.
N.W. Cape
New Caledonia
Loyalty Is.
Tongatabu
Shark B.
TROPIC OF CAPRICORN
AUSTRALIA
Brisbane
R. Darling
Norfolk I.
Perth
Lord Howes I.
Kermadec Is.
Australian Bight
Sydney
C. Leeuwin
North C.
Melbourne
North I.
AUSTRALASIA
TASMANIA
Hobart Town
Wellington
South I.
NEW ZEALAND
Chatham I.
Cornwallis Is.
Stewart I.
Bounty I.
Snares
Antipodes I.
Auckland I.

Fig. 1.—Map showing the Natural History Province of New Zealand and Australia. (*The black line limits the latter.*)

Other animals will explain the matter as well. The ape and monkey are restricted by seas and high mountains, and some cannot live beyond forest land. The deer and horses can roam very widely, but wide seas and very high mountains will be barriers to them, and this is the case with the elephants also. Again, all ancient animals belonging to genera and species now extinct, but which possessed structures similar to those birds and quadrupeds, were subject to restriction, and would be characteristic of their natural history provinces. On looking at a map, some of the natural history provinces can be discovered at a glance; for instance, those of New Zealand, Australia (Fig. 1), and South America. The first two are surrounded by wide seas, and the last has sea on all sides but one, where there is the neck or isthmus of land which separates it from North America, in the north of which there is a high table-land which has already been described.*

It is evident that only birds of flight could wander to and from New Zealand, and that all other terrestrial creatures of any importance cannot leave it. When the first colonists went to New Zealand they found that there were no quadrupeds there; and indeed, all that are there now, have been introduced by man. They found, however, a multitude of birds, and one kind interested them much. It was a small fowl with a long beak, a large body covered with silken or hairy-looking feathers, and long legs. But it could not fly, and its wings were small and useless. Its toes were not webbed. This diminutive wingless bird was called apteryx, and the natives knew it as the kiwi; it ran in a crouching manner amongst the ferns and grass, and it could neither fly nor swim. Subsequently more species of the wingless birds were found on the islands, and of course it is conceded that they are the characteristic animals of the natural history province of New Zealand. They are not found anywhere else on the globe, and they cannot get beyond the barrier which now surrounds (in the shape of a deep ocean) their province.

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* "Science for All," Vol. III., p. 354.

Shortly after this bird had been noticed, a son of the late Dr. Mantell, a very distinguished geologist, found in a swampy place in the northern island of New Zealand, the thigh, and leg, and side-bones of some gigantic creature, and they were sent to Professor Owen for examination. He saw that they were not the bones of a mammal or a reptile, but that they once belonged to a gigantic wingless bird, to a bird which would be as much restricted within natural boundaries as the little apteryx. Since that time fourteen different kinds of these great birds, some ten feet in height, have been found in New Zealand, and they have been collected under the head of the genus Dinornis (or "mighty birds"). Amongst the bones of these huge extinct birds, those of the modern apteryx were found, and also bones of great penguins. No great mammalia have been found whatever. The interest of the discovery of these numerous extinct birds has been increased by the finding of relics of man in association with them. Men killed and cooked the birds and grilled their great bones, for these are found charred by fire and near native implements. And the Maoris tell how a great bird called the moa, scampered over the ferns and plains in the days of their forefathers.

These great birds, recognisable by their skeletons, some of which are in the British Museum, have not been found out of New Zealand. Hence they were the characteristic animals of the province of New Zealand during the last geological age, and they lasted down in diminishing numbers to the age of man, and then became extinct. Now it is evident that, size being left out of the question, the present species of apteryx, which lived with the giants of old, represents the old and new characteristic animals of the province, and that there has been a persistence of the shape and method of life, or what is called "type," in the same area or country during some geological changes, and certainly during a vast lapse of time. New Zealand, as it now is, could not support the existence of nearly a score of kinds of huge birds, plentiful in individuals, besides a vast number of others. Was it ever a larger island? It is a curious fact that although the separation and distinctness of the animals of New Zealand and Australia are perfect, the river fish of New Zealand should somewhat resemble those of South America. Indeed, there is reason to believe that in the Tertiary period there were lands, not connected in a mass, between South America and New Zealand, and that these islands once formed part of a much greater surface. It was the diminution of this country by the sinking of much of the land near the coasts, that probably caused the extinction of the great birds, and man completed it. The answer relating to former provinces, so far as New Zealand is concerned, is that the former province was restricted, and on nearly the same area as the present, and there were characteristic animals on it of the same type as the present ones.

The next natural history province to be considered is the Australian, and it is very interesting because it is so perfect now, and was so during ages gone by. A map of the Southern Hemisphere of the globe will show the vast island-continent of Australia standing by itself in the midst of the great ocean. Its limiting barrier is sea. But there is an island to the south called Tasmania, which is separated by deep water and broad straits from the mainland. This island is considered to belong to the Australian province. To the north and north-east of Australia there are many islands, some small and others very large, such as Melville and its associated islands close to the coast, the great islands of New Guinea and Celebes, and the Aroo Islands, separated from Australia by Torres Straits, in which there are small islands. To the west of these are the islands of Timor, Floris, Sumbawa, and Lombok, all in a line. Now to the west of this last-named island, separated by a narrow strait of a few miles' breadth, is a small island called Bali, and it is the continuation southwards of the great line of islands of which

Sumatra and Java are the most important. Now a line drawn on a map through this narrow Strait of Bali, and made to pass along eastwards so as to include New Guinea and Celebes, and then to go south and curve round Australia and Tasmania, until it comes to Bali again, is one which includes the whole of the Australian natural history province. Mr. Wallace, many years ago, discovered that this narrow Strait of Bali separated and limited two of the grandest natural history provinces, and that there was hardly a quadruped on the Australian side which resembled any on the other or Asiatic side. All the islands mentioned within the "line" that environs the Australian province have peculiar animals, which differ in every respect from those to the west and north, or in Asia and its islands. The tiger, elephant, and monkey exist on one side of this limit, and the kangaroo tribe on the other, and the creatures are never found associated.

It will be noticed that the surface of ground occupied by the Australian province is great, and all the land surface, and formerly much more in some directions, belongs to the province which is characterised by one great sub-order of quadrupeds and five families out of six of another. Except a few small, rat-like animals like those of the rest of the world, and which very likely have been introduced, all the native mammalia of this great province are pouched—marsupial animals. Here, again, is a defined province with characteristic animals. It is necessary to examine these, and then to pass on to the considerations regarding the province which existed there in the last geological age and its special animals.

If the kangaroo (Fig. 2) be taken as the example of a pouch-bearing animal—one of the *Marsupialia* (from *marsupium*, a pouch)—its appearance can be readily remembered. In its natural position—the body half erect—its huge hind limbs, great tail, and small fore limbs, long muzzle, and ears are very characteristic. It seems to squat on its tail, and to be supported by long legs on very long and slender feet. The fur is short and close, and may be of all tints from light brown to dark brown and red. The creature hops like a huge rat, and evidently the fore limbs are not of much use to it during locomotion. They have important uses, however. The wrist is very movable, and, by employing both hands, food can be taken to the mouth, and the claws are weapons of defence. But the most important use is in relation to the most interesting part of the construction of the animal and its life-history. The female may be seen at the Zoological Gardens with two or three little heads poking out of her body below the chest, and if watched, as many little kangaroos will pop out of a kind of bag, and after awhile will go in again. This is the pouch which gives the name to the order of which kangaroo, or, more properly, Macropus (great foot) is a genus. The animal cleans out its pouch, opens it, and even places the young therein with the aid of its fore limbs. There are two bones, one on each side of this pouch, which, moreover, contains the teats in the female, called marsupial bones. These last are present in the male also. An anatomist, on examining the skull of a marsupial like the kangaroo, finds the front teeth widely separated from the hind ones, and that the back part of the lower jaw is turned in, or inflected. There is no probability of mistaking the skull, limb-bones, and body-bones of a marsupial; they are distinct and different from those of a tiger, elephant, or ox.

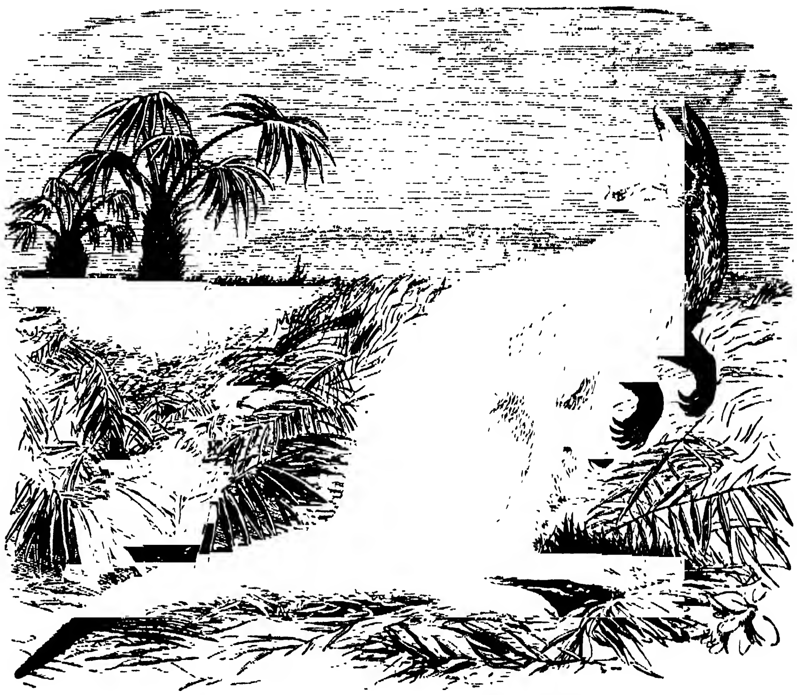

Fig. 2.—Kangaroo.

There are many kinds of kangaroo; some inhabit plains, others rocky places, and there are tree kangaroos, with powerful tails, in New Guinea. Some small ones are very rat-like in shape, and are about the size of a rabbit. They are the potoroos, and they are rather nocturnal in their habits, making little nests of grass. They are none the less marsupial.

Another group or family of marsupial animals leads a totally different life to the kangaroo's, and has its structure modified, to assist it in the struggle for existence. The wombats (Fig. 3), or *Phascolomides* (pouched mice), are about two to three feet long, and they have a short stump of a tail, a low body, and strong and not very unequal limbs, ending in broad extremities furnished with claws. They are goers on all fours, and have plump bodies covered with fur. Their head is short in front of the eyes. Running well, the wombat takes to the ground, and burrows with great rapidity. Now this animal has an inflected lower jaw, marsupial bones, a pouch, and the fore-limbs have the power of wrist movement, and the hinder also of similar ankle movement. The teeth are remarkable for their number in relation to the kangaroo's, and the front ones are very much like those of a rodent animal such as a large rat.

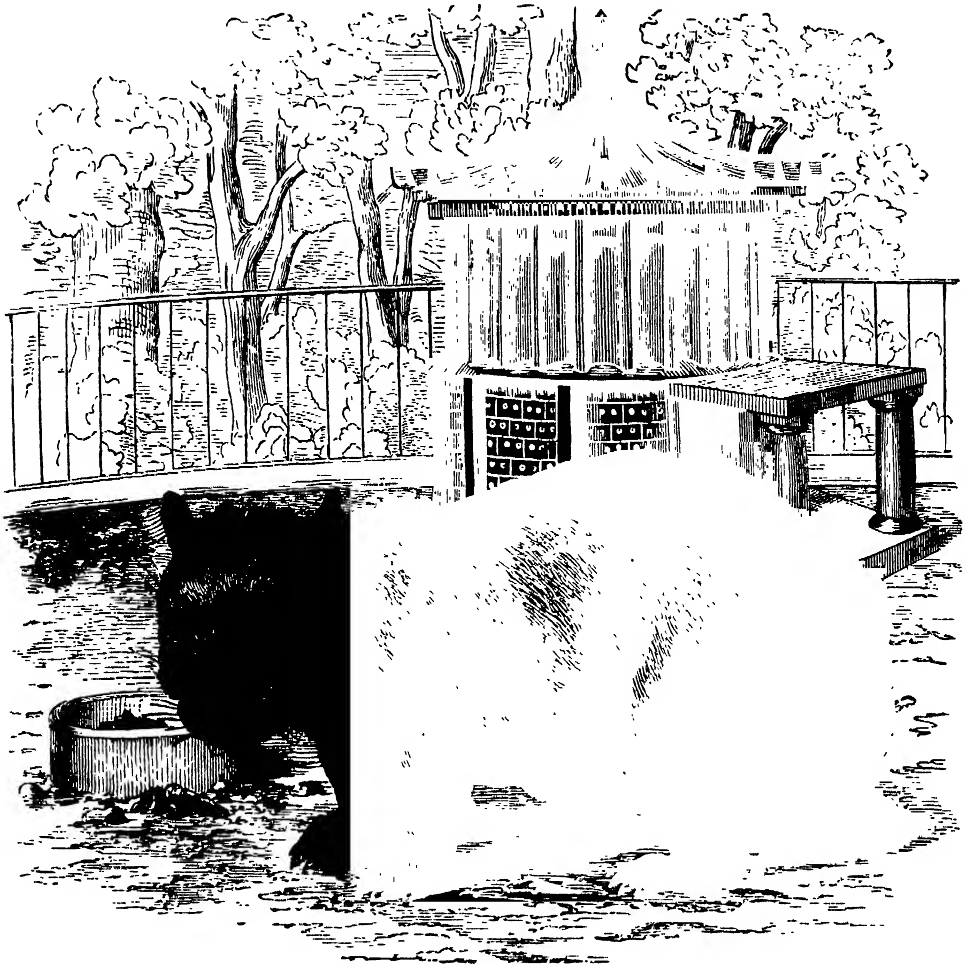

Fig. 3.—The Wombat.

The next family of marsupials is that of the phalangers, of which the vulpine phalanger (the brush-tailed opossum of the colonists) may be taken as the type. They live about the great gum trees, and are very active during the night, but sleep by day, and their shape is something between that of a squirrel and a marten. They feed on vegetable matter, as well as on insects and small birds, and although they lead the life of a tree animal, they are pouched, and have the inflected jaw, and other marsupial peculiarities. They have a fine tail. Some of these phalangers have the skin of the flanks so well developed, that it enables them to use it as a parachute, and fly from branch to branch. Some of these animals are not larger than mice. Closely allied to these is a small, long-tongued, curiously-fingered marsupial, called the tait or Tarsipes, and its shape recalls that of a lemur known as Tarsius.

The pouched badgers, of which the bandicoot is an example, are burrowers, and both root and animal eaters, and they are as interesting as the next group, the pouched ant-eaters. The Tasmanian devil, a carnivorous and very ill-tempered animal, is also a marsupial; but its teeth are more after the plan of those of the ordinary carnivora, of the Asiatic province for instance. Its fellow carnivore is the dog-headed Thylacine, or pouched dog, or zebra-wolf, which walks in a semi-plantigrade manner, and is very dog-like; but there is a pouch present, and the other characters of the order. A little group of pouched weasels also exists.

Thus it will be seen that whilst in other parts of the world, animals which lead the lives of flesh-eaters, grass and leaf nibblers, root gnawers, fliers, and insect devourers are of different orders of mammalia — such as the carnivora, ruminantia, rodentia, and insectivora—those which lead these very diverse lives in the Australian natural history province are included in one order, the marsupial type being modified to carry out their special life-histories.

It is a remarkable fact, and one which relates to the ancient history of the globe, that one family of marsupials which is not found in the Australian province is known on the American continent. It is that which contains the opossums. Hence the Australian province is characterised by the existence in it of all the families of the marsupial animals except the opossums.

Besides the marsupials already mentioned, there is another great group of them which is found only in the Australian province, and it contains the Echidna and the duck-billed Platypus. These extraordinary animals are found in Tasmania, Australia proper, New Guinea, and other islands of the province.

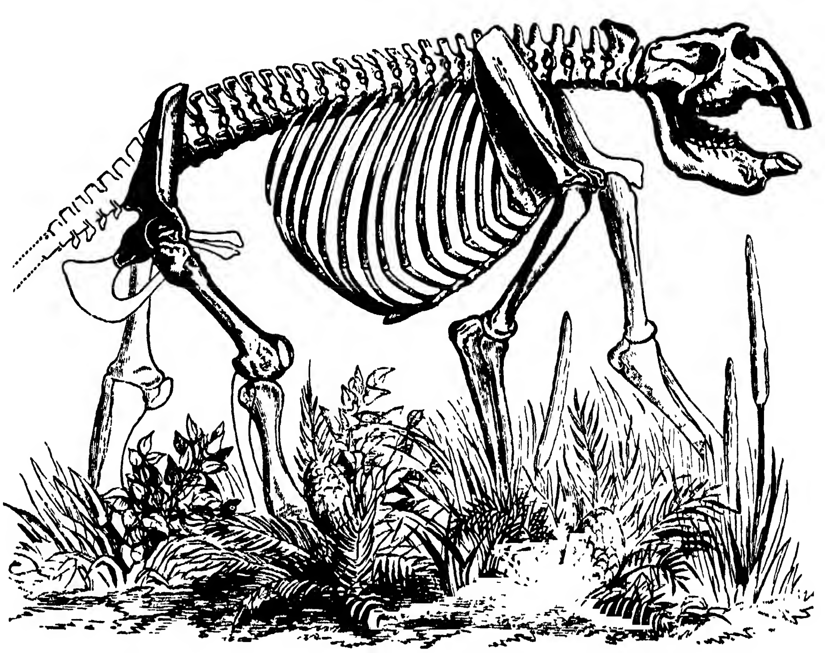

Fig. 4.—The Diprotodon. (*Restoration of the skeleton, after Owen.*)

What were the animals of this province before the present state of things and in the last geological age? Is there any relation in the scheme of nature here, between the animals of the past and present?

Caves in the Wellington Valley, bogs under the soil in the Darling Downs, gravels near Melbourne, and many other places, in positions indicating a considerable antiquity, wherever science has searched in the South Australian provinces and Queensland, have yielded bones in abundance. These belonged to animals that lived when the country was less worn down than it now is, but their examination proves that the old Australian natural history province had the same characters as the present.

One of the first results of the examination of these bones by Professor Owen, was the discovery that they one and all belonged to animals, which, had they been living, would have been classified in the same great marsupial group which contains the modern characteristic fauna of the Australian natural history province. Not a trace of the bone of a tiger or elephant, or of any animal which lives on the farther side of the natural limit and barrier of "Wallace's line," was found, and not a trace of any extinct creature resembling them. The pouched animal was as characteristic of the Australian province in those ancient days as it is now. Most were gigantic in size, and most died from off the surface of the earth during the last great modifications of the surface of the globe which initiated the present physical geography of the region. The natural history province was limited then, as now, although the nature of the countries and their extent within the limit differed; that is to say, the sea between the islands was dry land, but in the midst of Australia, where there is now the great central desert, there was sea.

There was no difficulty in distinguishing amongst the bones, those of creatures which if they were now living would be classified with the kangaroos or *Macropodidæ*. But they were gigantic in size, far exceeding the dimensions of the great kangaroo; they were fashioned on the same plan, and were jumpers on their hind feet, grass and leaf eaters, and they had the characteristic pouch-bones. Some very well marked great kangaroos lived in Australia before the existing state of things, and with some of those kinds which have perished, and are not now in existence. Even the tree kangaroo, which is now restricted to New Guinea, had forerunners on the mainland; for animals classified by Owen under the genera Protemnodon and Sthenurus, the last remarkable for its great and strong tail (*sthenos*, strength, *oura*, tail), belonged to this clumsier kangaroo of the forest. Fossil bones of an extinct kind of kangaroo rat were found, and also many of the next great family of marsupials or the wombats.

Amongst the many remarkable fossil remains found in the Wellington caves, Darling Downs, and Mount Macedon, Melbourne, and the Condamine River gravels, were skulls, back and limb bones, and teeth of a huge animal larger than any other from the Australian province. When put together and measured, the bones belong to a skeleton which was (without the tail) nearly eight feet in length, and five feet six inches in height. The tail was probably long and kangaroo-like. The great skull, three feet in length and nearly as much in height, seems all face, so little space is there for the brain at the back of it. There are two front teeth in the upper and the same number in the lower jaw, and they are enormous in size, even in relation to the great size of the jaws. The grinders are distinct from these, and form a set; the last ones being six inches long, which could champ up and down, but not move with the jaw from side to side. A large arch of bone protected the principal muscle, the temporal, which moved the lower jaw up and down, and this jaw had the characters of the marsupials. The openings for the eyes are large, and there are strong dents at the back of the head for the insertion of the muscles which come from the spine to enable the head to be moved and supported. The mouth is huge, but the structure of the teeth proves that they were used to nibble, gnaw, and champ small trees, boughs, and leaves. A strong spinal column exists, and the ribs included a capacious chest. Behind there are wide haunch bones, and thus the shape of the body was very much after the fashion of animals which at the present day consume large quantities of vegetable food. The creature had long blade bones, and, strange to say, although the skull is made after the kangaroo model to a certain extent, the fore limbs, instead of being short and smaller than the hind ones, are long, and as large, in comparison to the hind legs, as are those of most quadrupeds of other kinds than marsupials. The animal walked on all fours, and was not mainly supported by the hind limbs, as is the kangaroo. Moreover, the fore-arm bones had the power of moving so as to turn the wrist up and down, as in the kangaroo, and this gift undoubtedly had to do with the animal's pouch, and the nursing of its young therein. Great as were the hind limbs, still the thigh-bone was the largest in them. There was a knee-cap, and the animal bent its knees as the elephant does. From the huge size of the front teeth, the animal was called Diprotodon by Owen, who described it. (Fig. 4.) But how did diprotodon move and feed? It ran, but did not jump, and its vast bulk—for it was as large as a rhinoceros—would prevent it from moving more rapidly than at a sharp trot. The feet have not been discovered, but doubtless they had nails. The shortness of the neck is remarkable, and diprotodon could not graze unless it went down on its knees, or unless it had a trunk on its head. Probably it lived on the shoots and leaves of trees, and it was, therefore, a slow-moving, on-all-fours, vegetable-eating marsupial. This vast creature became extinct before man appeared on the Australian district. It had no means of defence, and its small amount of brain indicates a very simple method of life. Small skeletons have been found in some caves in which a great carnivorous marsupial lived, and probably they had been brought in by it as prey. The anatomist, under the guidance of our great teacher, Richard Owen, can distinguish much that is of surpassing interest about these great bones. Some, in their shape and position, recall those of animals still lower in the scale of classification, and others indicate that if the diprotodon had lived to the present day, some of the structures of the wombat would be recognised to exist with those of the great elephantine-looking kangaroo.

Another animal lived at the same time as diprotodon and roamed over the same line of country, leading very much the same kind of life. It was smaller than its huge companion, but had the same shape. The front teeth differed, however; for instead of the tusk-like incisor of diprotodon, this animal had a smaller tooth with a limited fang. The skull was great, but there was less face in front of the eyes, so that it resembled the modern wombat in that particular more than the long-faced kangaroo. The arch of bone on the side of the face, which protected the muscles of the lower jaw, was larger than in diprotodon. It was a vegetable-feeder, which moved on all fours, like diprotodon, and Owen called it the Nototherium (*notos*, south). This creature became extinct with its greater companion. Although it was a marsupial animal, it has left no descendants. One extinct wombat was indeed gigantic, being of the dimensions of a tapir. It was, of course, not a burrower: but there were smaller ones, resembling much the modern wombat, which probably led its particular method of life. The phalangers were a family in those old days as now, and one skeleton found, resembles that of the modern vulpine phalanger. Moreover, there is a fossil which resembles the bandicoot in its skeleton.

Again, there were fossil species of the carnivorous marsupials, and one is referred to the native Dasyure or " native devil," whilst another appears to have belonged to an animal resembling the dog-headed thylacine. Both of these animals now live in Tasmania only; but formerly, and during the age of the great marsupials, they lived on the mainland.

At the present time, the distinctions between the jumping or saltigrade and the on-all-fours-moving marsupials are evident, and the kangaroo and the wombat illustrate this. But in the past age there were animals which linked the two groups together. The extinct great kangaroo was one of the distinct kinds, and diprotodon, moving like an elephant, was the other. Moreover, several kinds of kangaroo-like things had shorter and stouter feet, and longer fore limbs in relation to the great hind ones than in the kangaroos.

The last set of bones which have to be mentioned as having been found in the Australian caves belonged to animals now extinct, whose skulls were very remarkable. They were characterised by two great front teeth in the upper and lower jaw with sharp points. Then came some very small teeth, and then above and below and on each side of the mouth, an enormous tooth with a long cutting crown. To this succeeded, in the lower jaw, a couple of sharp crushers. The muscular markings on the outside of the skull were great, and the animal was large and powerful. The bones had the characters of those of the pouched animals, and Professor Owen called this one, the pouched lion, or Thylacoleo. It was probably the great enemy of young and invalid kangaroos and diprotodonts, but it is extinct. Finally a fossil echidna, or "porcupine ant-eater," has been found in the Darling Downs, and also remains of wingless birds, resembling the emu and cassowary.

Thus Australia as a natural history province, was as well defined and characterised by marsupials and echidnas in the last geological epoch as it is now. The present assemblage of animals there, is separated by seas in some instances, for certain kinds are peculiar to New Guinea and Tasmania, for example; but formerly that was not the case, or not so much the case. It appears that some of the existing kinds lived in the remote past with the gigantic marsupials, and thus there has been no cataclysm which destroyed those great forms from off the surface of the earth. They probably died off, from change of climate and restriction of their roaming-grounds; and one of the great causes was the uprise of the floor of the great central sea, and its becoming a waterless, dry, torrid, barren desert. Thus the New Zealand and the Australian provinces tell the same kind of story.

FLINT.

By the late Professor Barff, M.A., Christ's College, Cambridge.

On the English sea-shore, particularly at Ramsgate and Margate, where chalk cliffs are found, you will see many irregularly-shaped stones quite white on the outside. The white is often powdery and loose: it will mark your clothes. It is evidently chalk, and the cliffs about are chalk, so it is plain that these stones come out of it. Moreover, if you examine the cliffs themselves, you will see in various places stones like them, standing partially out of the rock, and lower down, at the bottom of it, long layers of similar stone material will be observed to run along in the chalk for a great distance. Sometimes, two or more layers are above another, with an interval of a foot or two between them; and these layers vary in thickness in different parts, from half an inch to one or two inches.* If, now, you throw one of these white stones on to a larger stone with sufficient violence, it will break, and the inside will be found to be nearly black; but observe the broken surfaces: you will find them to be smooth and undulating. If, however, you strike the stone with a hammer, so as to break it into several pieces, you will observe that the surfaces of all the pieces are similar, but that some of them will have sharp edges—sharp enough to cut wood. Now these stones are called flints, and all common stones which break in a similar manner are composed mainly of the same material, whatever may be their colour. This cleavage, as it is called, has received the name conchoidal, from the resemblance of its surface to that of an oyster or other bivalve shell. Most of the flints found in the chalk are black inside. If one of them be put into a fire, in its hottest part, and be left there for some time, it will be found to have become nearly white. Flint is very hard, and although it can be broken easily by a smart blow with a hammer, yet it is extremely difficult to reduce it to powder; but after it has been heated to a white heat in the fire, it is much more easily powdered. If, when it is white hot, it be quickly taken out of the fire, and be thrown, white hot, into cold water, it will on examination be found to be full of cracks. It can then be powdered in an iron mortar with much greater ease. This is an experiment which it would be well for those to try who are anxious to thoroughly follow out and understand this paper. Why does the flint become white when heated? It is because it owes its black colour to the presence of organic matter, and this, in the fire, is burned into carbonic acid gas by the oxygen of the air, and goes away. And why does it crack? Because the flint is an aqueous formation; that is, it is formed in the presence of moisture. Sometimes there will be seen yellow spots on the outer surface of such a flint. These are due to the presence of oxide of iron. It would be well, when the opportunity offers, to break other stones, and examine the broken surfaces—for example, those smooth grey or brown oval stones which are so common on the sea-shore—and in no case will a cleavage be found similar to that of flint. But there are many stones differing in colour, although they are generally of a brown or yellow tint, which break in exactly the same way that flint does. These too are flints, and they are coloured by metallic oxides, usually by oxide of iron. There are also to be found on the beach very beautiful white stones: these are generally very pure flint. Alum Bay, in the Isle of Wight, is famous for its coloured sands, and among these is one which is quite white. All the sands—in fact all proper sands—are of the same composition as flint, but they, like the various-coloured flint-stones, are coloured with organic matter, or by metallic oxides. The white sand, however, is free from all impurities, or nearly so, and is largely used in a manufacture which will be treated of at another time.

The chemical name for flint is Silica. It is an oxide of a non-metallic element called Silicon. Twenty-eight parts by weight of silicon unite with twice sixteen, or thirty-two parts by weight of oxygen, to form this substance. Its composition is invariable, so that wherever flint or silica be found, it always contains the same proportionate weights of these elements, although the appearances which it assumes may differ greatly. In order to facilitate the representation of chemical substances, simple or compound, as well as to show *simply* chemical changes, certain symbols are employed to represent these bodies in the *quantities* in which they act upon one another. These symbols have, to those who have not studied chemistry, a very alarming appearance, and when they are introduced into a paper which is intended for the general reader, they often prevent him from attempting to read it. Now, really, this seems to be a mistake, for when understood as to their meaning they are not only not difficult, but render much more simple the explanation which they are intended to give.

Just read back a few lines, and you will find that many words are used to explain the composition of silica. The "symbol" SiO_2 represents all this. These "symbols" have been frequently used in the course of the chemical discourses which have appeared in these volumes; and though they have been explained at the time, yet it may be useful at the present stage of our studies to enlarge on the important question of chemical nomenclature somewhat more than has hitherto been done. Let us examine SiO_2, and see if it is difficult to be understood. "Si" are the two first letters of the word silicon, but they do not stand for it; they mean more than the simple element—they mean twenty-eight parts by weight of it. Whenever "Si," therefore, appears in any chemical book, whether alone or with other symbols, that is its meaning. "O" means sixteen parts by weight of oxygen; therefore "O_2" means twice that quantity, and "O_3" three times sixteen parts, and so on. The small numbers, which denote the number of times which the symbol to which they are attached is to be taken, are usually put after the symbol, and below it. This is the best method, because then they cannot be confused with algebraical powers, which they do not resemble at all. In some books on chemistry, however, they will be found put above, but this makes little matter, if it be remembered that they do not mean the same thing as similar figures do in algebra. Before the conclusion of this paper, other opportunities will occur of further explaining the use of symbols. We have already considered briefly only one form in which silica, or flint, occurs in nature.

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* As the geological relations of flints have already been discussed in "Science for All," Vol. I., p. 66, we confine ourselves mainly to their chemistry.

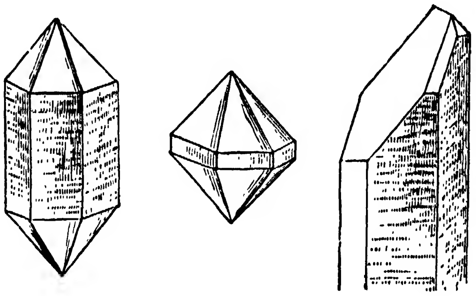
Fig. 1.—Crystals of Quartz.

For the future the word silica will be used, and not flint, as that is only the name for one form of it. Silica exists in nature in many forms: sometimes it is crystalline, and sometimes amorphous; that means not crystalline. Flints are amorphous, but occasionally if a flint be broken it will be found to contain a cavity full of beautiful colourless crystals. Such flints are often found on the sea-shore. The cavities in flints are often large, and the bottoms or bases of the crystals adhere to their sides, the points projecting towards the middle of the cavity. Now and then the crystals in smaller cavities overlap one another, and at first sight cannot be easily distinguished. The crystals in these cavities are not always white; in yellow or brown flints they may be tinted. When silica occurs crystallised, it is called quartz. Very large crystals of quartz have been found, and may be seen in almost every public and private collection of minerals. The crystalline form of quartz is a six-sided prism, with a six-sided pyramidal top (Fig. 1). Quartz crystals are extremely hard; they will readily scratch glass, though they will not cut it as the diamond does. Many valuable stones used for ornamentation are composed of silica. Chalcedony, jasper, opal and agate, are all silicious minerals. It will be explained at a future time how the various beautiful forms in agates are supposed to occur. Silica is also a principal constituent of granite, and it, with other substances, forms felspar; also a constituent of granite which is largely used in the manufacture of porcelain. It also occurs in all the stones which are used in building. It is the material which largely assists in binding together the particles of the different substances of which they are composed. Silica is also found in plants, and in very many minerals, some of which consist almost entirely of it. It forms also the framework or skeleton of many sponges; it assumes very beautiful forms in the microscopic diatom; it is deposited from the boiling springs of Iceland, and is found in small quantities in sea-water, and all sorts of fresh-water. We will now proceed to consider the chemical properties of silica. It is not acted upon by any of the ordinary mineral acids, such as sulphuric, hydrochloric, or nitric acid. There is, however, one acid which attacks it readily: it is called hydrofluoric acid. If a piece of flint be boiled for any length of time in either of the three first-mentioned acids its weight will not be diminished, nor will silica be found in the acid by any of the tests which will be presently explained. Alkalies, however, act upon it, and dissolve it. If you take some of the flint which has been heated and thrown into cold water, and powder it in an iron mortar, and then boil it for some time in a solution of caustic soda or potash, you will, on examination, find that a considerable quantity of it has been dissolved.

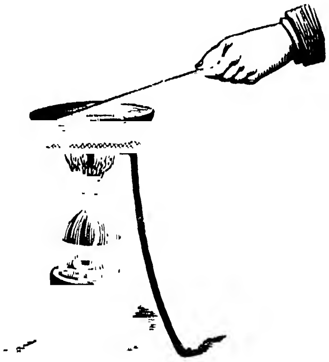
Fig. 2.—Dissolving Flint.

To perform an experiment to illustrate this, a small silver dish should be used, as neither caustic soda nor potash acts on this metal; but as silver

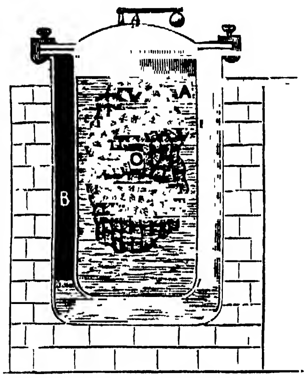

Fig. 3.—Section of a Digester.

dishes may not be easily obtained by some of my readers, a Berlin dish will do. Arrange it as shown in Fig. 2, and after boiling for an hour, filter off the liquid, and when clear add to it, first, some hydrochloric acid, until a piece of blue litmus paper when dipped into it becomes bright red, then add ammonia solution till it smells of ammonia, and a white precipitate will be thrown down. This precipitate will be silica in a form very different from that in which it existed in the flint. Blue and red litmus paper can be obtained at any operative chemists, as can also necessary apparatus. The reason why a Berlin dish for this experiment is not as good as a silver one is, because the dish itself contains silica, which is dissolved in small quantities by the alkali (potash or soda); but for the purpose of this experiment that does not very much matter, as a much larger quantity of the flint will be dissolved, it being in the form of a fine powder, thus exposing a much larger surface to the action of the alkali. For commercial purposes, where silica is largely used, this operation is performed, but under different conditions. The vessel in which the flint and alkali are heated is called a digester; it is a closed vessel, constructed as shown in Fig. 3. It is made of strong iron which will stand a pressure of eighty or ninety pounds to the square inch; it consists of two vessels, one placed within the other, leaving a cavity of from five to six inches between them. B represents this cavity. The charge of flint is put into a net C made of iron wire, (the flints having been heated and thrown into water, but not ground); it is suspended in A, the solution of caustic potash or soda, made strong, is also poured into A, the whole is covered by a strong iron lid, which is tightly screwed on the top so as to close both cavities, and then steam is blown into B through the pipe D. Because the vessel is closed the temperature of the water in A is raised far above that of ordinary boiling water, which is 212° Fahr., under a pressure of 70 lbs. that is, about 121° C. or nearly 250° Fahr., and at this temperature the flint is dissolved very rapidly, and forms a solution which in consistency resembles treacle, though its colour is not dark. If, instead of *boiling* the flint in a solution of alkali, it be mixed in the state of powder with excess of carbonate of soda or of potash, or better, with a mixture of both should it be desired to perform the experiment at a low temperature and more rapidly, it will, on being heated, form a kind of glass. This is done by putting the mixture into what is called a London crucible (a small cheap one about four inches high will do). The lid should be fixed down with a little fire-clay—fire-clay can be bought at oil shops—rub some down with water to the consistency of putty, and plaster it round the lid, and fill in the opening where it covers the crucible; let it dry slowly in front of the fire. When the fire-clay luting, as it is called, is dry, put the crucible into the centre of a hot kitchen fire, and pile coal or coke round and above it, and leave it for an hour or two, then take out the crucible, and when it is cold it will be found to contain a substance like glass. Break the crucible, take out the glass, powder it, and boil it in water for some time, the glass will dissolve, *i.e.*, the silica will be in solution, and its presence can be detected by the method already described. The reason why carbonates of soda and potash are used together is, that a mixture of them acts more rapidly and at a considerably lower temperature than either of them does when used alone; and the reason why a carbonate is substituted for the caustic alkali is, that at a high temperature the caustic alkali melting would attack the silica and another constituent of the clay of which the crucible is made, and probably destroy it. It has been several times stated that in these operations the silica has been dissolved: this is hardly a correct statement; however, it was necessary to make it until the time arrived for an explanation of what really takes place. Let us take the case where caustic soda is used:—soda, for that means caustic soda, (washing soda is often called soda, this is wrong: washing soda is carbonate of soda), is a compound of a metal sodium with oxygen and hydrogen. Natrium was a name formerly given to this element; Na, its first two letters, has been adopted by chemists to represent 23 parts by weight of it; O, we have already seen, represents 16 parts by weight of oxygen, and H, the initial letter of the word hydrogen, is the symbol for one part by weight of hydrogen; therefore $NaHO$ represents $23+16+1=40$ parts by weight of caustic soda, or, as it is called in chemical books, sodic hydrate. When it is desired to represent 80 parts of this substance, $NaHO$ is taken twice, and this is written thus: $2NaHO$. When $2NaHO$ is boiled with silica we represent the mixture as $2NaHO+SiO_2$; the water in which it is boiled is not represented, as it remains unchanged, except that it evaporates and fresh water has to be added from time to time; the water employed should always be distilled water, which can be obtained at the chemist's. And now let us consider the change which takes place, and how it should be symbolically represented. A direct union takes place between the silica, the sodium, and the oxygen, therefore we get, Na_2SiO_3, and H_2 and O are thrown out, but they unite chemically, which is expressed by writing them together thus, H_2O; now if we add the weights of these together we shall find it to be $2 + 16 = 18$; that is, H_2O represents 18 parts of the compound which oxygen and hydrogen form when they unite in these proportions, and this substance is water. The whole operation is represented symbolically by an equation, so called because the weights of the substances on both sides of the equation are equal, and it is written thus:—

$$\overset{\text{Caustic soda.}}{2NaHO} + \overset{\text{Silica.}}{SiO_2} = \overset{\text{Silicate of soda.}}{Na_2SiO_3} + \overset{\text{Water.}}{H_2O}.$$

It will now be seen that, after the experiment has been performed, the silica does not remain as silica, but is changed into a new compound. Silica cannot be dissolved in water, though it can be held in solution in water, as will be shown hereafter; and it is not dissolved by caustic soda, but is changed by it into another substance, which is soluble in water, and so is said to be dissolved in it. The new compound which is formed is called silicate of soda, and the symbol for 122 parts by weight of it is Na_2SiO_3. In the second experiment, where carbonate of soda is *fused* or heated in a crucible with powdered flint, the changes which take place are somewhat different. C, the initial letter of the word carbon, is the symbol for 12 parts by weight of it. Carbonic acid gas is formed by the union of C with O_2, and is written thus, CO_2, and when CO_2 unites with oxide of sodium, Na_2O, it forms carbonate of soda, whose symbol therefore is Na_2CO_3. We therefore express in symbols the mixture of flint and carbonate of soda thus—$Na_2CO_3+SiO_2$; and here let it be understood that whenever the sign + is used, it implies that the bodies which it connects together are simply mixed, not chemically united, but that when the symbols are put together without this sign, they are in chemical union. The action of heat, at a high temperature, on this mixture is to make the silica drive out or expel the carbonic acid, and take its place by uniting with the soda, and the following is the symbolical representation of this action:—

$$\overset{\text{Carbonate of soda.}}{Na_2CO_3} + \overset{\text{Silica.}}{SiO_2} = \overset{\text{Silicate of soda.}}{Na_2SiO_3} + \overset{\text{Carbonic acid.}}{CO_2}$$

or, as it is sometimes written—and it is a clearer way of showing the change—

$$\overset{\text{Carbonate of soda.}}{Na_2OCO_2} + \overset{\text{Silica.}}{SiO_2} = \overset{\text{Silicate of soda.}}{Na_2SiO_3} + \overset{\text{Carbonic acid.}}{CO_2}$$

If the weights of each substance on each side of the sign = be added together, they will be found to exactly correspond, and it will be observed that the resulting compound, silicate of soda, is exactly the same as that formed in the first experiment. Silicate of soda and silicate of potash are now largely used. A fuller description of them will be given at another time. If to a solution of either of them hydrochloric acid be added, a gelatinous precipitate will be formed, if the solution of the silicate be strong, but if the solution be dilute, no precipitate will appear, although a chemical change will take place; but on the addition of ammonia to the dilute solution with hydrochloric, a white precipitate will be formed, more or less abundant, according to the strength of the solution. It will be here necessary to consider the change which takes place when the hydrochloric acid is added, and to explain the different results produced in the two solutions. Hydrochloric acid is formed by the union of chlorine gas with hydrogen. Cl, two letters from the word chlorine, are used as the symbol to represent 35·5 parts by weight of it. In forming hydrochloric acid, one part by weight of hydrogen unites with 35·5 of chlorine; so the symbol for 36·5 parts of hydrochloric acid is HCl. When this acid, therefore, is poured into a solution of silica of soda, the mixture and action are represented thus:—

$$\overset{\text{Silicate of soda.}}{Na_2SiO_3} + \overset{\text{Hydrochloric acid.}}{2HCl} = \overset{\text{Chloride of sodium.}}{2NaCl} + \overset{\text{Water.}}{H_2O} + \overset{\text{Silica.}}{SiO_2}$$

Silicate of soda and hydrochloric acid give chloride of sodium, water, and silica. Chloride of sodium is common table-salt, which we eat; but the water ought not to be separated by the sign + from the silica, because they really unite together chemically when the change takes place; so that we should say, when mixed together, silicate of soda and hydrochloric acid produce chloride of sodium and silicate of hydrogen; and this latter body is called hydric silicate, just as the first is called sodic silicate. The reason why no precipitate is formed when the solution of sodic silicate is dilute, is that although the same change exactly takes place, and silicic hydrate is set free, the silicic hydrate remains dissolved in the excess of hydrochloric acid present, over that which is required to effect the decomposition, for silicic hydrate is soluble, to a certain extent, in the acid; but where the solution of silicate is strong, more silicic hydrate is formed than can be dissolved by the hydrochloric acid present. This can be proved by taking some of the gelatinous precipitate on the end of a glass rod out of the test tube in which the experiment was performed, and putting it, with more hydrochloric acid, into another test-tube, and boiling it for a short time; then filtering it, and adding ammonia, a similar precipitate will be given to that obtained on other occasions, showing that silicic hydrate has been dissolved, for hydrochloric acid does not ordinarily contain this substance.

It is now time to mention another name which is given by chemists to silica. It is called silicic acid. Now why should it be called an acid? It is not a liquid, as most acids we see are; it is not soluble, as are those acids, such as tartaric and citric acid, with which effervescing drinks are made; and it does not taste sour, as do all acids with which most people are acquainted. If you will look back at the symbolical representations already given and explained, you will see that in the last, silicic acid changes place with carbonic acid, and because it can do this it is rightly classed with the acids. Again, in the first experiment it is seen that it unites directly with the alkaline substance sodic oxide, formed in the decomposition by the expulsion of water from the sodic hydrate; and this, again, is another property which all acids possess of being able to unite with alkalies, or, as they are called, *bases*, to form compounds which are called *salts*. Silicic acid is what is called a *weak* acid. If you put it with carbonate of soda you can effect no change until it is heated to a very high temperature, and then it will, as has been seen, drive out carbonic acid and take its place. The following is a very interesting and instructive experiment to perform. Take some of the silicate of soda you have made, or, if you have not done so, get some at an operative chemist's, in solution, put it into a test-tube, and pass carbonic acid into it. The apparatus is shown in Fig. 4. Into the bottle A put some lumps of white marble, through the tube B pour in some hydrochloric acid, and carbonic acid will be given off. Pass it into the solution of silicate of soda contained in C, and in a short time a gelatinous precipitate of silicic hydrate will be thrown down. The equation representing this is as follows:—

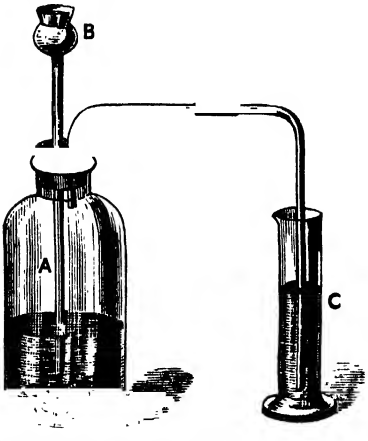

Fig. 4.—Experiment showing the Precipitation of Silicic Hydrate.

Silicate of Soda. Water. Carbonic Acid. Carbonate of Soda. Silicate of Hydrogen.

$$Na_2SiO_3 + H_2O + CO_2 = Na_2CO_3 + H_2SiO_3$$

You will observe that it is nearly the same as that representing the action of carbonate of soda on flint at a high temperature, only it is reversed. In that case silicic acid turned out carbonic acid, but here carbonic acid turns out silicic hydrate. A specimen of pure silica or silicic acid can be obtained in the following way:—Add to a solution of silicate of soda an excess of hydrochloric acid; then, when the precipitate is all formed, add a quantity of distilled water, and stir it about with a glass rod. This operation is usually performed in a beaker glass, which can be obtained at a chemist's. Allow the silicic hydrate to settle, pour off the water, and repeat the washing several times; then put the gelatinous mass, after filtering off the water, into a Berlin dish with some hydrochloric acid diluted with water, and boil it. This is to remove any metallic oxides, such as iron oxide, which might be present. Dilute with water, filter, and while it is on the filter-paper, wash it well with water; then, when dry, transfer it again to the Berlin dish, and heat it to a red heat; in fact, make it as hot as you can. The silicic hydrate will part with its water at a high temperature. H_2SiO_3, or H_2OSiO_2, will become $SiO_2 + H_2O$, which latter will pass off as steam. In the Berlin dish will remain a fine white powder, very light and easily blown away; this is pure silica, and is as insoluble in water or acids (except hydrofluoric acid) as flint itself. You will now perceive that silica, to be soluble in water or in ordinary acids, must be chemically combined with water—must be, in fact, silicic hydrate, and it is in this form that it is dissolved, and remains dissolved in ordinary waters,

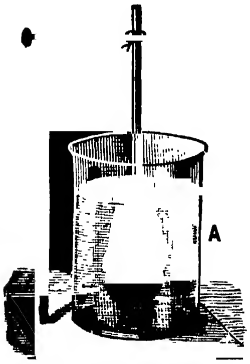

Fig. 5.—Experiment showing that a Liquid containing a "Colloid" Body will not pass through a Bladder.

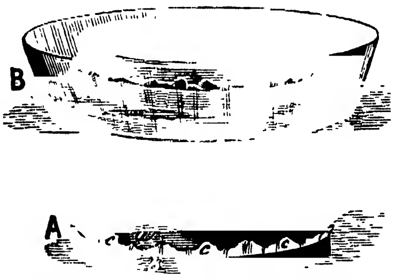

Fig. 6.—Experiment Illustrating the Property of "Diffusion."

though in very small quantities. Silicic hydrate is what is called a colloid body—that is, it is of a viscid, glue-like character, and this property is taken advantage of to separate it from certain other substances, so as to get it dissolved in a pure state in water. It is found that when certain liquids of different densities are separated by a bladder they mutually pass through it, the one into the other. When one of these liquids contains a colloid substance, it will not pass through the bladder. Suppose a coloured non-colloid substance be put into a bladder, and if the bladder be suspended in a vessel containing a colloid solution, the coloured liquid will pass through the bladder into that solution, but the colloid substance will not pass into the bladder. The arrangement for this experiment is shown in Fig. 5. A is a beaker glass containing the colloid solution, and B is a small bag made of bladder, containing the coloured solution. A very pretty experiment to illustrate diffusion is prepared as follows:—Put into a dialyser a solution of iodide of potassium, and into the vessel of water in which the dialyser floats some ordinary starch mixed with water—a small quantity of boiled starch will do—and into the starch in water put a few drops of *yellow* nitric acid (it must be yellow, and can be bought at an operative chemist's); in time the iodide of potassium will pass through to the starch; the yellow nitric acid will decompose it, iodine being set free, and the free iodine will colour the starch blue. For performing the experiment, to obtain a pure solution of silica, the dialyser to be used should be made of a ring of gutta-percha (Fig. 6, A, *a*) about two-and-a-half inches deep and less than a quarter of an inch thick, it should be five or six inches in diameter. Another much smaller ring should fit over it rather tightly (*b*). Stretch a piece of vegetable parchment (*c*) over the larger ring of gutta-percha, and then press the smaller ring over it: it will have the appearance of a tambourine. It is shown in Fig. 6, A. Now take some silicate of soda and dilute it, so that the solution does not contain more than five per cent. of silica. As it would be very difficult for an inexperienced person to determine this, if you dilute with water until hydrochloric acid gives no precipitate in the solution, for an illustrative experiment like this you will be near enough. Make the solution distinctly acid with hydrochloric acid: this will be proved by using blue litmus paper; then pour it to the depth of *less* than half an inch into the dialyser, and float it on the surface of distilled water in any convenient vessel (Fig. 6, B). After a short time it will be found that hydrochloric acid has passed through the dialyser into the distilled water, and this may be proved by taking some of it in a test tube, and adding a dilute solution of nitrate of silver to it, for immediately the two liquids come in contact a white precipitate will be formed. The water in which the dialyser floats should be changed twice a day, and tested for hydrochloric acid, and this should be repeated till nitrate of silver gives no precipitate in it. The liquid in the dialyser can then be put into a bottle, it will be found to be clear, and colourless, and tasteless; it will very *slightly* redden blue litmus paper, for now the silica is in position to manifest in this way its acid properties. If the solution contain fully five per cent. of silica, it will set to a jelly, if it be exposed to the air, in a short time, and this jelly will gradually contract and become hard. The writer has some which is so hard that it will scratch glass. When broken it shows the conchoidal fracture just as flint does. If the solution contain only four per cent. of silica, it may be kept for a long time, but at last it will gelatinise, and it should always be preserved in a stoppered bottle. While the dialysing process is going on, the dialyser should be covered with a sheet of paper to keep out dirt. It has been already stated that the only acid which will act on silica is hydrofluoric acid. It will be necessary to describe its composition and preparation. Derbyshire spar is well known to all, it is used for making all sorts of chimney ornaments, candlesticks, &c. It varies in colour, but is generally purple and semi-transparent. Its chemical name is fluoride of calcium; its composition is forty parts by weight of calcium, and twice nineteen parts of fluorine. Calcium is a metal which with oxygen forms lime. Ca represents 40 parts by weight, and F represents 19 parts by weight of fluorine, therefore 78 parts of fluoride of calcium will be represented by the symbol CaF_2. Hydrofluoric acid attacks silica, and glass contains silica, therefore it cannot be made in a glass vessel; lead or platinum vessels are used in its preparation. When the vessel is made of lead, it is usually of the form and construction shown in Fig. 7. A is the part which contains the mixture, B is the cover, and C the delivery pipe; the cover fits into a groove as shown in the section, and this groove is filled with strong oil of vitriol to prevent the escape of the gas; should the delivery pipe C require to be lengthened, this can be done by using a gutta-percha pipe, for this material is not affected by hydrofluoric acid, in fact it is always kept in solution in gutta-percha or lead bottles. The gutta-percha pipe can be connected to the lead delivery pipe by a small india-rubber tube connection. Coarsely-powdered fluor-spar and strong oil of vitriol should be put into A, and mixed quickly with a wooden or even a glass rod, for in the short time it would be in use, the glass rod would be only slightly acted upon; the cover should be put on as described, and the whole placed on a sand-bath, D; the temperature should be kept *low*. Hydrofluoric acid gas will at once begin to pass off, and it should be conducted into water contained in the bottle E. Hydrofluoric acid is very soluble in water, and in a short time the water in the gutta-percha bottle, E, will be saturated with it. It should be corked up at once, and with care will keep fit for use for a long time. In experimenting with this substance great care should be taken not to inhale the fumes, as they are very injurious, and equal care should be taken not to get any of the acid on the fingers, as it causes very unpleasant sores which are difficult to heal. A small experiment can easily be performed to show the properties of this acid. Get a clean leaden inkstand, such as is used in school desks, put into it a small quantity of powdered fluor spar mixed with strong oil of vitriol, and *gently* warm it over a lamp; stand it in a little sand placed on an iron plate: soon fumes of the acid will be seen to come off, remove the lamp, and place over the opening in the inkstand a piece of glass: in a short time the polish on the glass will be destroyed by the decomposition of the silica contained in it. If the glass be coated with wax or tallow, and designs be scratched through the wax down to the glass, it will be protected by the wax from the action of the fumes, which will only corrode the designs traced, so that they will be engraved into the glass. The explanation of the action of hydrofluoric acid on silica is very simple :—

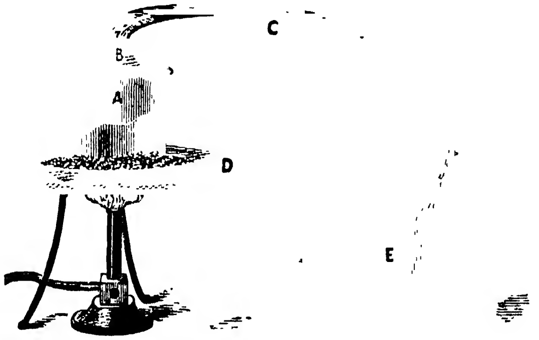

Fig. 7.—Experiment Showing the Preparation of Hydrofluoric Acid.

$$\overset{\text{Silica.}}{SiO_2} + \overset{\text{Hydrofluoric Acid.}}{4HF} = \overset{\text{Water.}}{2(H_2O)} + \overset{\text{Fluoride of Silicon.}}{SiF_4}$$

water, and a substance which is a gas, called fluoride of silicon, being formed. If this gas be made in a suitable vessel from which it can be led into water, it is decomposed, and a white substance immediately appears in the water. This white substance is pure silicic hydrate, and, when dried and heated to a high temperature to expel the water of the hydrate, becomes silica. This is the best way to prepare a sample of pure silica. The action of water on fluoride of silicon is thus symbolically represented :—

$$\overset{\text{Fluoride of Silicon.}}{3(SiF_4)} + \overset{\text{Water.}}{2(H_2O)} = \overset{\text{Silica.}}{SiO_2} + \overset{\text{Hydrofluo silicic acid.}}{2(H_2SiF_6)}$$

It will here be seen that one-third of the silicon in the fluoride unites with all the oxygen of the water to form silica, while the remaining silicon, the hydrogen of the water, and all the fluorine unite to form a new body, which is called hydrofluo silicic acid. The brackets used here imply, as in algebra, that the figure outside the bracket multiplies all the quantities within it. Thus, $3(SiF_4)$ is the same as Si_3F_{12}. Perhaps an apology is necessary for being so minute in one's explanations; but as some who will read this paper require such explanation, those who do not will pardon what is useful to others. Fluoride of silicon can be made easily with care. Take a common Florence flask, quite clean; it can be freed from oil by washing it with a strong solution of common washing soda, and be dried by warming it over a lamp, and sucking out the steam formed in it with a long clean glass tube inserted almost to the bottom of the flask. Care should be taken not to make it too hot, as the moisture condensing above in the cold part of the flask may run down on the hot part and crack it. To avoid this, the flask should be continually turned round while over the flame of the lamp. When the flask is dry, fit a cork into its mouth with a hole bored through it; put one end of a bent glass tube through the hole, then cause the other end to dip into a small Berlin crucible containing a little quicksilver, and which stands immersed in water in a beaker glass. In Fig. 8, F is the flask, D, the delivery tube, C, the cup of mercury, B, the beaker glass. When all is completed, detach the flask, and pour into it a little oil of vitriol. Use only enough to moisten the flask all over on the inside, and effect this moistening by turning the flask about. Then put in some finely-powdered glass, and shake it about: it will stick to the oil of vitriol, and will so line the flask. Then make a mixture of powdered glass and powdered fluor spar in about equal parts; put this into the flask, and pour in strong oil of vitriol, and shake gently till it makes a mass of the consistence of thick mud; cork up the flask and apply a gentle heat. Fluoride of silicon will be given off, and will pass through the delivery tube and bubble up through the mercury into the water, where it will be decomposed, each bubble of fluoride of silicon forming a bubble of white silicic hydrate. The reason why the flask should be covered with powdered glass is, that this may be attacked by the hydrofluoric acid before the flask itself. After a while the flask would be destroyed; therefore the experiment should not be continued too long. The mercury in the small cup is used to keep the water from the end of the delivery tube, for if this were not done, the tube would soon be choked up with silica, there would then be no escape for the gas, and the flask would burst. It is always well to have but a small depth of water over the mercury, so that under no circumstances could it be drawn back into the flask, for if water get into a flask containing hot oil of vitriol, a very serious explosion would take place. After the experiment is completed, the liquid in the beaker should be filtered from the silica and put into a stoppered bottle. It consists of a solution of hydrofluo silicic acid. It was necessary to follow the course adopted in this paper, and not to mention the element silicon until we had led up to the preparation of the substance from which it is obtained. If to hydrofluo silicic acid in a test tube a solution of a potash salt, say the nitrate, be added, a very strange-looking effect will be produced. There will be no apparent precipitate formed at first; but, on holding the test tube to the light, the liquid will appear opalescent. After a time, an almost transparent precipitate will be thrown down. Filter this off from the liquid, dry it, and it will be found to be a very fine and very beautifully white powder. This powder is fluosilicate of potash. If it be mixed with the metal sodium, cut into small pieces, and be put into a crucible well luted and heated to high temperature for about an hour, the result will be the setting free of the element silicon in the form of a dull brown powder, perfectly insoluble in water and in all acids except hydrofluoric. As this powder has no crystalline form, it is called amorphous silicon. It burns brilliantly in air, but more so in oxygen gas, and the result is a pure white powder, which is silica. But if some zinc be put into the crucible along with the mixture already described, and if it be heated to a temperature sufficient to melt the zinc, but not to volatilise it, for about one hour, crystallised silicon will be obtained. When the contents of the crucible are cold, they should be taken out and put into hydrochloric acid, which will dissolve the zinc, and the silicon will be left in dark, iron-grey crystals. These crystals are extremely hard and very brilliant. Crystallised silicon will not burn in air or oxygen, except at an intensely high temperature. In both cases, the decomposition which takes place is the same, and is very simple. The sodium takes all the fluorine which does not remain united with the potassium, and so the silicon is set free. To obtain the crystalline variety, zinc is used that the silicon may crystallise in it when in the melted state. There is still another form of silicon. It is called graphitoid, and is formed by heating strongly amorphous silicon in a platinum crucible. It would not be advisable for any one who is not expert at chemical manipulation to try to obtain silicon in any of its forms.

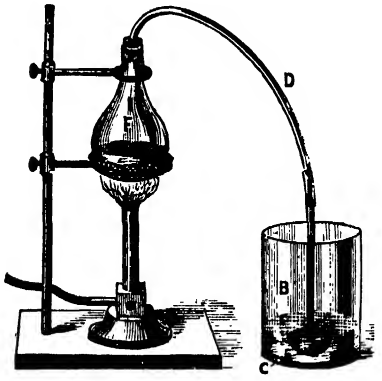

Fig. 8.- Experiment showing how Fluoride of Silicon is made.

THE OPTICS OF A LIGHTHOUSE.

By H. Trueman Wood, M.A.,
Secretary to the Society of Arts.

EVERYBODY is familiar with the general aspect of a lighthouse, and knows something of its construction and use, but probably very few who have not paid special attention to the subject know what a beautiful optical instrument a lighthouse lantern is. There are, indeed, not many better examples of the application of scientific research to practical purposes, and, as is not seldom the case, Science has herself been assisted in her progress by this practical application, for the inquiries directed simply after utility have advanced our knowledge of optics, and—though this is a portion of the subject not now to be dealt with—of acoustics also.

The lighthouse, in its perfect form, is essentially a modern invention. Fiery beacons of one sort or another there have been since commerce first began, but the modern lighthouse is of our own days. It is not so long ago since the last coal-fire beacon was abolished. In 1861 the "chauffer," at the entrance to the Firth of Forth, was lighted for the last time, after it had served for 180 years, and it was the last of its race in this island. These "chauffers," or braziers for burning wood or coal, were for long considered all that was wanted to warn the mariner from a dangerous coast, or guide him to a friendly harbour. Such a beacon blazed on the great Tour de Cordouan, the oldest of existing lighthouses, as it had blazed centuries before on the Alexandrian Pharos. It was hailed as a great improvement when in Winstanley's first Eddystone (1696) a number of tallow candles were substituted, and from that day to this the improvement has gone on. The history of this progress, however, we cannot now stop to trace, interesting as such a task would be. All that can be done in the few pages available for the treatment of the subject is to try and give some account of our present system—a system which owes its perfection to the labours of some of our ablest engineers and our greatest men of science.

Let us consider first what is the problem which the lighthouse engineer has to solve. He must obtain the most powerful light which science can afford him. He must avail himself of every fraction of that light, not wasting any on sky or land, but sending all out to sea, and to that part of the sea where the light is wanted. He must send it far over the water, to the utmost horizon which the lofty tower or cliff affords him, so that as soon as the sailor reaches that point where first the convexity of the earth's surface renders it possible, he must see the warning light. Lastly, after all these conditions have been satisfied, he must give each light a character of its own, or, at least, a character differing from that of any light sufficiently near for the two to be confounded.

When we consider how many and how various are the conditions to be fulfilled, it becomes obvious that our engineer's task is by no means complete when he has built a lofty tower on some storm-washed rock, or has set up a strong house on some almost inaccessible crag, hard as his task is often found in either case. With this earlier portion of his labours we have nothing now to do. Those who would learn how such difficulties are met and conquered may read the story—in each case by the engineer himself—of how Smeaton built the Eddystone and Stevenson the Bell Rock Lighthouse; while if they would know how modern engineering science has lessened those difficulties, they may study Sir James Douglass's account of the erection of the greatest of modern lighthouses, the New Eddystone, which replaced Smeaton's work in 1882.*

We will consider the apparatus employed to deal with the light before saying anything about the means by which the light is obtained, such an arrangement of the subject being, if less logical, certainly more convenient. It must be remembered that the apparatus will be the same, whatever be the source of light employed. All lighthouse lights, whatever be their power or intensity, may be arranged under one of two great classes—fixed or steady lights, and flashing or intermittent lights. The object of this last-named arrangement is obviously to fulfil the last of the requirements above stated, the bestowal of a special character upon the light. No other device has been found so effectual as this. The first suggestion that would naturally occur would be to give the lights different colours; but the use of coloured lights is liable to the very serious objection that a large amount of illuminating power is thereby destroyed. If we allow light to pass through a piece of red glass, we find that the light is, as we say, coloured red; but what does this mean? It means simply that of the infinite variety of coloured rays which fall upon the glass—the infinite variety which by their combination make up white light—only those which are nearly or quite red are allowed to pass. The rest are, for all purposes of illumination, practically lost. The glass might be of such a character as to allow only pure red to pass through it, but as a matter of fact ordinary "ruby" glass permits the passage of all the red, most of the yellow, and sometimes even of a minute portion of the green. Not only then is the ray coloured, but it is robbed of half its brilliancy. Suppose blue or green glass be used in the same way. We then get only the blue and the green rays, with such portions of the other coloured rays as the glass may be transparent to. But with them we have a further drawback. It is a common observation that nearly all artificial light has a yellow tinge. Translated into scientific language, this means that it is deficient in blue rays, in the more refrangible rays towards the violet end of the spectrum. It is therefore deficient in the very rays which alone can pass freely through blue and green glass, which is equivalent to saying that a powerful light on one side of glass of this colour will be a very weak one on the other. Nor have we yet done with the objections to blue and green. They are said to possess less penetrative power in fog (which is naturally yellowish in tint), so that they are visible at a much shorter distance. In consequence of all these drawbacks the use of colours, except for harbour lights, even of red, is looked on with small favour in this country. In France, red is used more freely, and when a light is caused to flash in turn red and white, most ingenious arrangements are employed to make the red light and the white of equivalent intensity. Were this not done, at a certain distance the red might be invisible, and the white alone would then be seen, the distinctive character of the lighthouse being—for that distance—entirely changed.

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* Report of the British Association, 1884, p. 590.

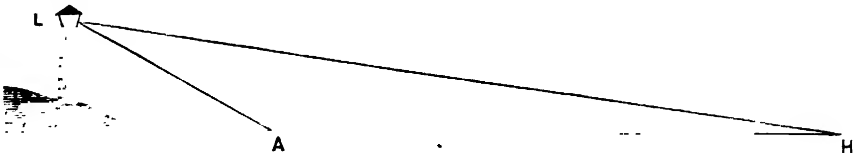

Fig. 1.—Diagram showing portion of Sea Surface illuminated by Lighthouse Rays.

If, therefore, we are not allowed to employ colour for sake of distinction, we are reduced to the two varieties of a fixed and a variable light. There can, of course, be only one sort of fixed light, but of intermittent lights there are many kinds. These, it may be well to say here, are also called "revolving" lights, since the occultation is now nearly always produced by the revolution of the system of lenses and prisms which surrounds the lamp, and not, except in a few exceptional cases, by means of screens, or by raising and lowering the brilliancy of the light itself.

But there are certain general principles which must be disposed of before considering the special characteristics of different forms of apparatus. Chief of all it is the great object of the engineer to collect the rays which radiate in all directions from the lamp, and to direct them upon the sea. Any source of light may be considered as the centre of a sphere formed by its rays. At the centre of the sphere there is brilliant illumination. This illumination decreases very rapidly as we leave the centre and pass towards the circumference. If a candle be set in the middle of a large room, a person sitting close by it can see to read; a few yards away the light is very greatly diminished, while at the end of the room there may be only a mere glimmer of light. The precise law which governs this diminution has been fully explained in a previous volume.* It will be sufficient for our present purpose to remember that light diminishes as the square of the distance. If we have a certain amount of light a mile from a lantern, at two miles we shall have a quarter of the light, at three miles a ninth, at four a sixteenth, at ten a hundredth. If, however, we can send all the light from the original source into one-half of the sphere, we shall at once double the light seen at any point; and if we can concentrate it all into a yet smaller portion of the sphere, the illumination will be proportionately increased according to the smallness of the portion which then receives light previously distributed over so much larger an area.

Now, broad as is the expanse of sea over which the warning beam has to be thrown, it really occupies but a small part of the imaginary sphere of light which we consider to be formed from the lighthouse as a centre. For simplicity's sake let us take a vertical section of our sphere, and treat the lighthouse as the centre of a great circle only. Then we may say that the surface of the sea, from the foot of the lighthouse to the horizon, subtends only a small angle at the lighthouse lantern. This may be made clearer by a simple diagram (in which, by the way, no sort of attempt has been made to preserve due proportion between the height of the tower and the distance of the horizon). In Fig. 1, L is the lighthouse lantern, H the horizon, and A the nearest point to the foot of the tower which it is necessary to light. Then all rays not included in the angle A L H are absolutely wasted, and it is evident that these rays form but a small portion of all those radiated from the lamp. Mr. Chance, in an admirable paper read a few years ago before the Institution of Civil Engineers,* stated that the horizon of a lighthouse 300 feet high (a little higher than the light on Beachy Head) would be 20 nautical miles (23 statute miles) distant; in other words, the lighthouse would be visible 20 such miles off, and that a distance of 15 miles (nautical), measured from the horizon towards the lighthouse, would subtend an angle of only 17 minutes. Now, there are 60 minutes in a degree, and 360 degrees in a circle, and it does not want any great arithmetical talent to see from this how small is the portion of the circle into which all the light has to be thrown.

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* "The Law of Inverse Squares:" "Science for All," Vol. III., p. 268, Fig. 7.

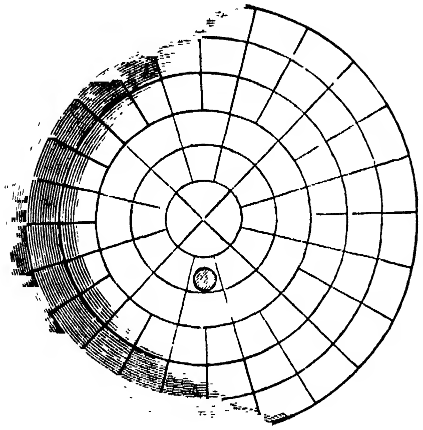
Fig. 2.—First Form of Reflector used for Lighthouse Purposes (Front view).

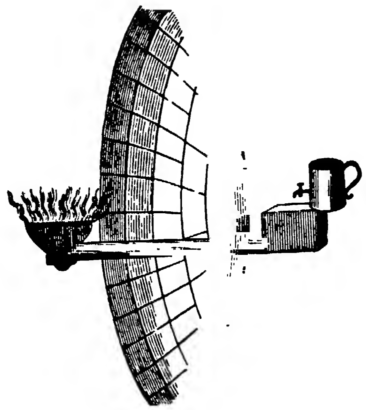
Fig. 3.—The same, side view, showing form of Lamp used in connection with the Reflector.

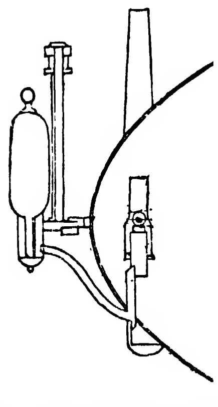
Fig. 4.—Capt. Huddart's Parabolic Reflector.

Now, how is all the light to be thus concentrated? The earliest and simplest plan was to put a reflector behind the lamp. The first reflector used was made of bits of looking-glass, fixed by means of putty in the interior of a wooden bowl. This was the invention of William Hutchinson, of Liverpool, and it was set up in that town in 1763. Fig. 2 shows the construction of the reflector, and Fig. 3 the rude lamp used with it. The little can at the back allowed oil to drip into a reservoir, so as to keep it up to the proper level as fast as it was consumed in the flame.†

Such reflectors as these were soon improved upon, and eventually the form of parabolic reflector shown in Fig. 4 was adopted. This arrangement originated with Capt. Huddart, an Elder Brother of the Trinity House. It is still used to some extent, and modifications of it are employed very largely. A parabolic mirror, it is perhaps unnecessary to remind the reader, reflects rays from a lamp placed at its focus in a parallel beam.

The employment of such reflectors was a step in advance, but it is not the most important which has been made. It is not by mere reflection from the surface of a mirror that the intense brilliancy of our great beacons is produced. A glance at the last diagram will show that a great number of rays are still free to strike from the lamp towards the sky and the ground, neither passing direct into the required path, nor being reflected into it by the mirror. Besides, no mirror, however perfect, reflects all the light which falls upon it. A certain proportion is absorbed, and therefore lost.

It does not require much knowledge of optics to perceive at once that a convex lens, placed in front of the lamp, would collect the diverging rays and send them out in a parallel beam. The ordinary burning-glass collects the parallel rays falling on it to a focus on the other side. Reverse this action, place the light at the focus, and the rays falling on the lens are parallelised on their emergence, as shown in Fig. 5.

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* "Proceedings, Inst. C.E.," Vol. XXVI. (1866-7). Those who wish for further information on the whole subject cannot do better than consult this paper, and two others—Henderson on "Lighthouse Apparatus," Vol. XXVIII. (1868-9), and Douglass on "The Electric Light applied to Lighthouse Illumination," Vol. LVII. (1878-9, part iii.). If they do not care to go back to original authorities, they will find much of the same information condensed in the excellent article on "Lighthouses" in "Spon's Cyclopædia."

† The reader will find a very clear account of the rise and present state of the science of lighthouse illumination in the introduction to Findlay's "Lighthouses of the World." This is based on a paper read before the Society of Arts, in 1857, by the late Mr. Findlay.

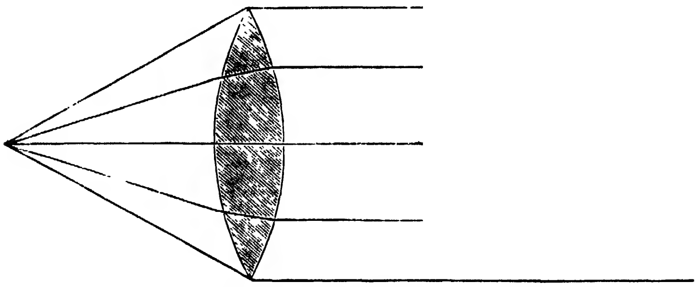

Fig. 5.—Showing Action of Light falling on a Convex Lens.

The same result is obtained by the use of a plano-convex lens, which is indeed only a double convex lens with one side having an "infinite radius" (Fig. 6).

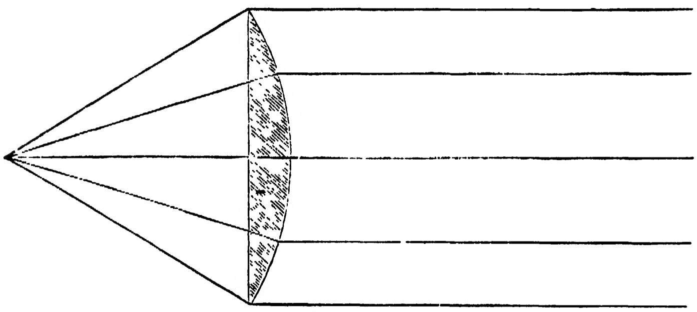

Fig. 6.—Showing Action of Light falling on a Plano-convex Lens.

But no sooner is this suggestion made than the objection occurs—"Unfortunately it would be impossible to make so big a lens as would be wanted, or to mount and use it if it were made." Quite so; but why should we have a solid big lens? The only really working part of the lens is, so to say, its skin. It is in passing from the air to the glass, from the glass to the air, that the ray is bent, and the only useful purpose of the solid central portion of the lens is to support its outer surfaces at the proper angle to one another. It might be thought that a shell of glass would be sufficient, but a little consideration will show that this is not so. The ray would be properly bent as it entered the shell, but it would be bent back again in passing from the glass to the air within the shell, and so no useful effect would be produced. The problem to be solved is, to bring the outer surfaces near to one another without altering the angle which they make with a ray crossing them. This seems difficult, but it is really very simple when once discovered. Imagine an ordinary plano-convex lens to be cut away in the fashion shown in Fig. 7. The sides make the same angle with rays passing through, and the effect is the same as before. Let the same principle be carried further, and we get Fig. 8, or by a more convenient arrangement, Fig. 9. In either of these it will be seen that a ray falling from the focus upon the lens meets with precisely the same angles as it enters and leaves the glass as if it had fallen on the surface of the solid lens shown in Fig. 6.

Fig. 7.—A Plano-convex Lens partly cut.

In practice, the lens is not cut out of the solid, but it is built up of suitable prisms. This building up, it may be noted, enables each part of the "polyzonal lens" to be separately adjusted, so that "spherical aberration" is avoided. Buffon, the great French naturalist, is believed to have been the inventor of this form of lens, his object being, by reducing the thickness of the material, to lessen the absorption of light. His lens was intended for a burning-glass. Fresnel, however, first applied the polyzonal lens to lighthouse purposes, and he therefore is rightly considered the father of the modern "dioptric" system.*

But even with a lens in front of our lamp and a reflector behind, we should not have mastered all the rays. There will yet be some which pass out in the space between the lips of the reflector and

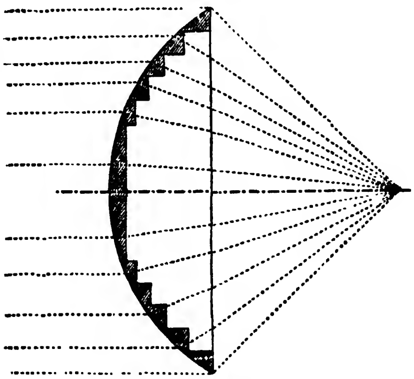

Fig. 8.—A Plano-convex Lens cut away more than in Fig. 7.

Fig. 9.—Arrangement of Plano-convex Lens.

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* *Dioptric* acting by refraction; opposed to *catoptric*, acting by reflection. *Catadioptric*, acting by refraction and also by reflection.

the rim of the lens. To render these available, another optical principle has to be called into play —that of total reflection from the internal surface of a prism.

This phenomenon of total reflection is worth a little consideration. When a ray of light passes obliquely into a prism, its course is bent, it is refracted; as it passes out of the prism through one of its other sides into the air it is refracted again. But suppose the angle at which the ray meets this second side to be so oblique that if it passed out without refraction it would just clear the side; what then is the effect of refraction? Why, the ray does not get out at all. It is reflected off from the inner surface of the glass, as if the layer of air next that surface had been a layer of quicksilver; and not only so, but the whole ray is reflected, none being absorbed, as is the case with the most perfect mirror. This important fact can be readily verified by any person without a prism or any special apparatus, since the same effect is produced when light passes up from below through the surface of still water. A visitor to any of our large aquariums looks through the window at the side up against the surface of the water. He will see the rocks at the back perfectly mirrored on the surface—so perfectly that he will not be able to tell where reflection begins and the object reflected ends. If a fish be swimming near the surface, he will see reflected above it a second fish, apparently back downwards. The reason for this is that light is reflected from the rocks or the fish against the surface, and is again reflected from it to the observer. Or, place a shilling in an ordinary tumbler half full of water, hold it so that a good light falls upon the shilling, and incline the glass towards yourself, keeping it a little above the level of your eyes so that you can look up from below at the surface of the water; you will see a reflection of the shilling, as bright as if you were looking at the shilling itself. The rays of light, instead of being reflected directly from the shilling into your eye, strike the water surface, and are reflected therefrom, without loss, into the eye.

This power of total reflection is, it will be seen at once, a most valuable one for lighthouse purposes. If a prism, such as is shown in Fig. 10, be interposed in the path of a ray striking obliquely upwards from the lamp at F, the ray will pass through the side C D, say at *f*, it will be slightly refracted, and will strike the side A D at an oblique angle at *f′*, so that it will meet the third side A C at *f″*, and will there again be refracted as it passes out into the air. The side A D is formed as a portion of a parabola, so that all the rays are parallelised and reflected in a direction at right angles to the vertical line *a b*. A series of such prisms is set above the lens, and a similar series below, in the manner shown by the sectional view (Fig. 11), and by the front view (Fig. 12).

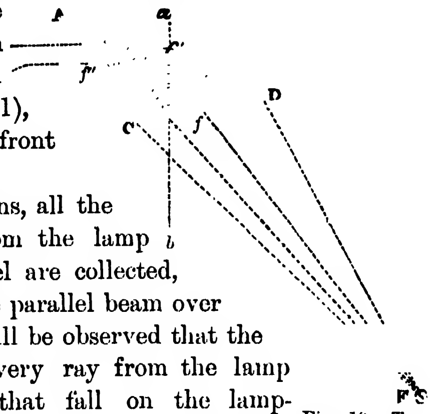

Fig. 10.—Total tion by a Prism.

By this means, all the rays falling from the lamp upon the panel are collected, and sent in one parallel beam over the sea. It will be observed that the panel takes every ray from the lamp (except those that fall on the lamp-stand, or which strike the chimney above) that comes within its breadth.

When, indeed, we speak of a parallel beam, it must be understood that it is only approximately parallel. For it to be absolutely so, it would be necessary that all the illuminating rays should proceed from a mathematical point. As a fact, they generally proceed from a large flame, and, consequently, rays proceeding from the outer edges or from the top or the bottom of the flame, strike the refracting apparatus at a different angle to that formed by rays which start from the central point. The result of this is a very considerable divergence, and practically the beam of light from a panel, such as that shown in Fig. 12, is a long, narrow cone, rather than a parallel band. This, far from being a drawback, is an advantage which would have to be sought for by special arrangements did it not arise naturally.

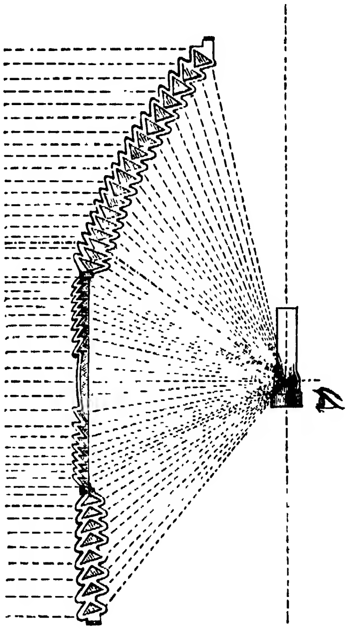

Fig. 11.—Sectional Vi above and below

There is also a further application of the same principle of total reflection from the internal surface of a prism, in the reflector which is now used under many circumstances in place of the original metallic mirror. This reflector is shown in Fig. 13. At D a number of prisms are set so as to surround the flame, and each prism is arranged to reflect back into the flame the rays which fall upon it. The ray thus reflected passes through the flame, and acts precisely as though it originated from it; going on to the system of lenses beyond, it adds its quota to the brightness of the issuing beam. The precise way in which the reflection takes place will be seen by an inspection of Fig. 14, in which a ray, B, starting from the lamp, enters the prism at C, is reflected at D and E, and leaves the prism at F. The arrows show the direction of the path.

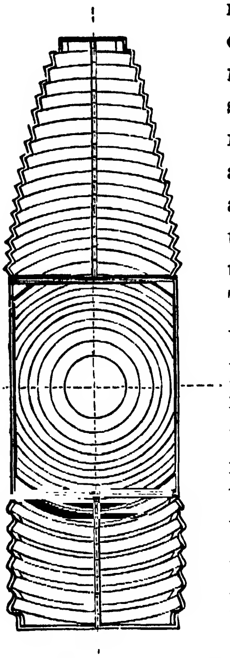

Fig. 12.—Front View of Panel showing Prisms arranged above and below the Lens.

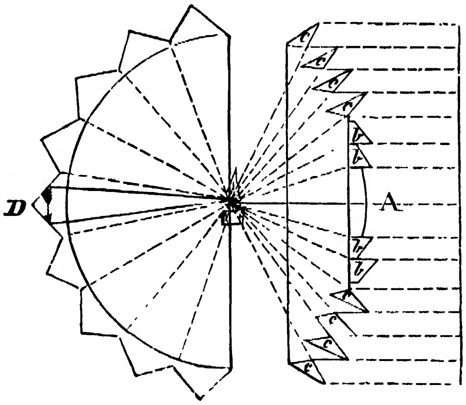

Fig. 13.—Prism Reflector.

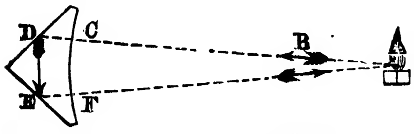

Fig. 14.—Explaining the Mode of Reflection in Prism Reflector.

It will have been noticed that in Fig. 11 there is something more shown than a section of the prisms and lens. Outside the whole arrangement is a vertical rod with a sliding piece upon it. Behind the lamp is figured an eye. This shows the method adopted for adjustment. The origin of this device is interesting, as showing the advantage which sometimes arises from the attention of an ingenious man being directed to a subject with which he is more or less unfamiliar. Many of our greatest inventions have been made by men who were ignorant of the routine of the trade or science with which their invention dealt—have, indeed, been made because of their ignorance. From 1858 to 1861 a Royal Commission was examining into the condition of our lighthouses. Mr. Campbell, the secretary of the Commission, was a photographer. When some question of adjusting the prisms was under discussion, it occurred to Mr. Campbell—who was accustomed to look at the images of objects formed by lenses—that by placing the eye in the position usually occupied by the lamp, and looking at the image of a distant object formed by each prism, the path followed by rays of light in travelling from the distant object through the prism to the lamp could be observed. This would be the same as the path followed by a ray from the lamp falling on the distant object. By adjusting the prism this ray could therefore be directed on any distant object. Owing to the small angle which, as previously stated, the sea surface subtends at the lantern, it is found that if the light can all be directed upon the horizon, sufficient light is actually thrown on all the intervening space of sea. Consequently, by adjusting the prisms so that they all reflect the image of the horizon to the focus of the lamp, the greatest efficiency of the whole apparatus will be secured. But this was not all. While the prisms were being thus adjusted at the Whitby lighthouse, it luckily happened that a fog came on and obscured the horizon. It was necessary either to interrupt the work or to provide a substitute for the horizon. Such a substitute was found in a staff like that represented in our figure. The spot where the horizontal line from the centre of the lens would cut the staff was ascertained, the staff was graduated by calculation, and the prisms were adjusted accordingly. When the horizon again became clear, it was found that the staff had done its work accurately, and that the prisms set by its aid were all in their proper positions. After this it was evident that the adjustment could be effected at the factory, and this is now done. Each prism is accurately formed for its own place, according to careful calculations, but it is adjusted by actual experiment, so as to give the best results. This is a work of great nicety, and has to be performed with exceeding care. The best position once found, the prism is fixed in the frame in that position.

Up to the present we have been dealing with a vertical section through the lamp, looking at it from a point on a level with it. Let us take a horizontal section, also through the centre of the lamp, so that we may consider ourselves as looking directly down upon it from above. The lantern, we will say, is eight-sided, and is one in which no reflector is employed, so that from each of the sides there pours forth a great band of light, in a direction at right angles to that side, and of a breadth equal to the side. It is not worth while to make a diagram to show that these bands do not cover the whole surface of the sea. They must leave between them great angular spaces of darkness. The bands radiate from a centre, and as they stretch away from that centre the spaces between them grow larger and larger. A ship sailing by the lighthouse would cross the bands of light; she would for a while be in a bright space, and then for a while in a dark space. To those on board the effect would be that they would see the lighthouse at times and lose sight of it at other times. The ship, obviously, too, might sail up one of these bands of darkness towards the lighthouse, and might never see the light at all. This would certainly be a fatal objection. But if the whole system be caused to revolve about the centre where the lamp stands, the broad bands of light will sweep over the sea, and the spectator on a distant ship will be brought in turn into the bright beam, and into a dark space. To him the result will be that he sees a light for a brief space, loses sight of it, then sees it again, and so on. In fact, the light will be to him occulting or flashing.

Fig. 15 shows the arrangement adopted for the purpose. The whole system of eight panels is mounted so that it is capable of revolving round and round the lamp in the centre, which is fixed. The revolution is effected by clockwork, driven generally by a weight. Sometimes the gearing goes wrong, and then the lighthouse-keeper has to work the apparatus round by hand, turning it by means of a winch, hour after hour, the whole night through. Such an apparatus as the one figured above is termed a "holophote," because it uses all the light of the lamp, this word being derived from the Greek, and having such a signification. Supposing the occultation were produced by screens, passing in front of the light, such a term would be inapplicable, because a large portion of light would be poured on the back of the screen, and lost. If the screen revolved entirely round the light, it would always have a certain amount of the light thrown upon it, and thus a portion of the light would always be doing no work. In a holophotal revolving apparatus all the light is always being employed, and inasmuch as the light taken from the dark spaces is added to the bright spaces, these latter have an increased brilliancy. A revolving light therefore is brighter than a fixed light of the same "order," because the same quantity of light is distributed over a smaller area.

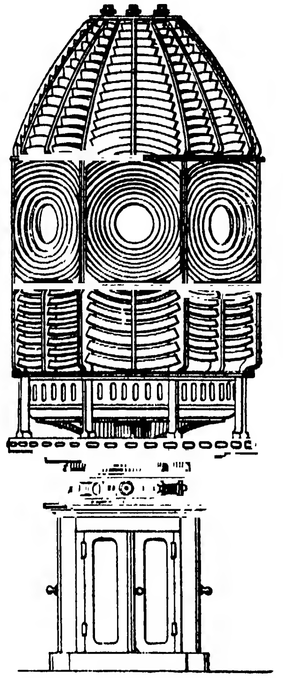

Fig. 15. — Arrangement of an Occulting or Flashing Light.

There is a certain peculiarity about revolving lights which is worth mention, especially as it distinguishes them from those not very frequent cases in which screens are employed. The light in them is never eclipsed quite suddenly. It wanes away and waxes again. This is due to the divergence of the rays from their theoretical path, the path they would follow if the refracting apparatus were absolutely true, and the source of illumination an actual point.

But it is possible to do more than give flashes of light separated by similar intervals of darkness. The lenses may, without difficulty, be made to give two, three, or even four flashes in rapid succession, followed by a longer interval of darkness. This beautiful device produces what are called "group-flashing" lights, lights in which "groups" of flashes alternate with dark intervals. The precise way in which this is effected must, with many other interesting details, be omitted for want of space, but it may serve to give some notion of the method adopted, if it be said that the panel which would give one long flash is replaced by two or more smaller panels, set at an angle to each other, their inclination being so slight as only to give a very brief separation between their respective flashes.

The group-flashing system gives a very characteristic light, and one not to be confounded either with a fixed light or with one which flashes at equidistant intervals of time. It also permits of great variety. It is further said to fulfil all nautical requirements. It is simple and intelligible.

The flashes are so close together that the sailor can "take a bearing" as readily from a group as from a single long flash. The signal is rapidly made and completed, and the sailor has not to wait for it to be repeated before he can be quite certain. If he catches the light and begins to count in the middle of a group, he may have to wait for the group to recur before he can be quite sure that he recognises it; but this is the longest delay he can be put to. Various proposals for more elaborate codes or systems have been put forward, but it is objected to all of them that they are too complicated or too slow. It was long ago proposed by Mr. Babbage that each lighthouse should have a number of its own, and should flash in proper order the units of that number. Thus, lighthouse No. 75 would give seven flashes, and then, after an interval, five more. Sir William Thomson has more recently suggested the simpler method of using the Morse telegraphic code, dots and dashes; short flashes and long ones. There is something very taking in the notion that every lighthouse should stand up over the sea, and proclaim in unmistakable language, "I am the Eddystone;" "I am the Start;" "I am the Lizard;" and so on. As it was ably put by Mr. Preece, the well-known Post-Office electrician, at a meeting of the Society of Arts, every telegraph-office in the kingdom has its own short signal, why not every lighthouse? If the Edinburgh station has to be called to attention, the clerk at any other station simply "calls" along the line, "E H," "E H," "E H," two dots and a dash (- - —), and every other clerk who hears him knows that it is Edinburgh which is wanted. The Eddystone would in like manner call E E, E E, E E, or two dots (- -), which in lighthouse language would be a pair of quick flashes. Every sailor who knew the code would at once perceive that the light giving two quick flashes was the Eddystone and nothing else; not the Start, which would give, say, three shorts and a long (- - - —), for S T; or the Lizard, which would perhaps be denoted by a single letter L (- — - -), as the addition of (— - -), to make L D, would involve too complicated a signal.

But, then, would every sailor know the code? and, knowing it, could he read it under the conditions in which it has to be read? Could he tell longs from shorts, and count flashes, when it is all he can do to see the light at all? Could the rough seamen who navigate, not the Queen's ship or the Cunard liner, but the collier or the coaster, read the signals? The Elder Brethren of the Trinity House assert that they could not, and will have none of Sir William Thomson and his scheme. They declare that they dare not venture on anything more complicated than the group-flashing lights, and so the matter rests. That this is not a mere reluctance to try fresh inventions we may feel sure, from the character for progress which the Trinity House has won. Perhaps, however, they may some day be induced to give the Morse code a trial, and then practice may decide where theory seems to be pretty equally balanced.

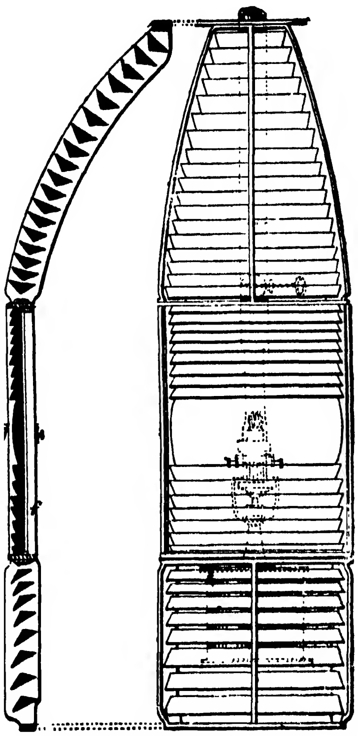

Fig. 16.—Front View and Section of a Fixed Light.

But if the arrangement previously described is not suited for a fixed light, how is the principle to be applied in that case? What we want to do is to parallelise the rays horizontally only; to send out a horizontal band of light that shall cover the sea in all directions between the lighthouse and the horizon. We want, in fact, a disc of light, or a large portion of a disc, not a series of separated bands radiating from the central point. Now, supposing we have a light, the section of which is the same as the section shown in Fig. 11, but having such a section, not only through the axial line of the panel, but at every part of the panel. It is evident that this will produce the required result. Let us imagine that Fig. 11 is revolved round a central line passing vertically through the centre of the lamp. We shall then have a light made up of panels of the shape shown in Fig. 16, which represents both the section and the front view of a panel produced as above described. In this the central line becomes a portion of the cylinder, and the curved prisms above and below are replaced by straight prisms of the same shape. All the component parts of the panel are in fact arranged symmetrically with reference to a straight line, instead of being so arranged with reference to a point in the centre of the lens.

Such are the two great classes of lights—fixed and revolving. It is easy to see that many combinations other than those already described are possible. One of the simplest of these is shown in Fig. 17, in which the panels of the shape used in revolving lights alternate with panels of the shape used in fixed lights. The result of this arrangement would be flashes of considerable brilliancy, with very short intervals of darkness before and after each flash, and during the remainder of the time a steady light of considerably less brilliance than that of the flash. Devices of this sort are much more in favour with the French administration than with our own Trinity House, and the French have adopted more elaborate arrangements than have yet been ventured upon in this country. As before mentioned, they also are fonder of colour than ourselves, and by thus ringing the changes upon the fixed and steady lights, white and red, they have a much larger range for variety. It is needless to observe that all this variety is obtained by means of a greater complication.

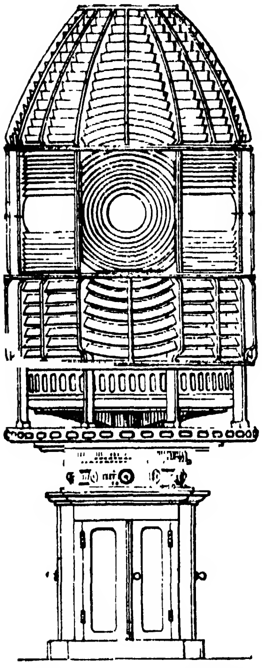

Fig. 17.—Light with Combination of Panels used in Fixed and Revolving Lights.

Now, although the principal systems of light have thus been dealt with generally, it must be understood that every light has its own special duties to fulfil, and must be adapted accordingly. One may be required to throw its light on every side; another may have half its horizon on sea and half on shore; a third may have to light up a narrow channel; a fourth may have to light a portion of the sea and a narrow channel on either side, in which case, probably, much greater brightness will be required for the channels than for the sea. In each case the simple arrangements selected as typical for description have to be modified by altering the shape of the refractors or by the application of reflectors.

In many cases a second light can be usefully applied to mark the proper course of a vessel, or to indicate a rock or other obstacle. Instead of a second lamp, some of the light of the main beacon can be utilised for this purpose. The reflector behind the lamp is then caused to direct the rays downwards, or in any direction required, upon a second reflector, which sends them out to sea. In some cases this second reflector is placed on the rock itself, and the apparent effect is produced of a light so situated; more generally, however, the second reflector is placed in the lighthouse itself, in the chamber below the lantern. Such an auxiliary light may well be coloured red, as it is not required to be visible at very great distances. A good example of this may be seen in the lighthouse at Bull Point, near the mouth of the Bristol Channel, and a few miles from Ilfracombe. The main light gives three quick flashes, followed by eighteen seconds' darkness, every half-minute. Below this is a small red light, which serves to mark the position of the Morte Stone, a dangerous rock some little distance out from the shore. This light is produced by a prismatic reflector at the back of the lamp, which sends all light falling on it vertically downwards through an opening in the floor of the chamber. The rays then fall on a second similar reflector, which throws them horizontally outwards through a red window. Nothing can be simpler than this arrangement, or more effective.

To meet the requirements of different localities, so far as the power of the light goes, there are six "orders" of lights. The apparatus for the first or largest of these is about nine feet high and six feet across. They decrease in size gradually to the sixth order, which is a small harbour light.*

Having thus discussed—briefly and cursorily indeed, but as fully as our limits permit—the methods employed for dealing with the available light, we must now consider the second important point—the sources from which the most powerful light may be derived. Nor have the advances of science been less helpful to lighthouse engineers in this department of their work than in that with which we have hitherto been occupied.

How successfully the whole subject has been treated is shown in a striking manner by some calculations made by Sir J. Douglass, the engineer of the Trinity House. His experiments gave as the equivalent of the light of the first Eddystone

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* Henderson: "Proceedings of the Institution of Civil Engineers" (Vol. XXVIII.). It may be worth stating that the cost of a lighthouse apparatus and lantern of the first order varies from about £3,000 to about £4,500, according to the tariff of the principal makers in this country.

(1696), 24 standard candles or modern light units. The use of oil lamps and reflectors gave in 1810 the equivalent of 1,125 units; the employment of dioptric apparatus in 1845, 3,216 units; and the substitution of an improved lamp in 1872, 7,325 units. In the new Eddystone two superposed lights are employed, and the light from these together amounts to 159,000 units, or 3,280 times the original light. The oil lamp of the South Stack gives a light of 169,360 candles, while the electric light at the Lizard is equal to 330,000. At this last-named station the mean intensity of the luminary alone, without the optical apparatus, is 8,751 candles.

There are in practice only three sources from which this enormous amount of light can be obtained—oil, gas, and electricity. At present, the first is the one most used. An oil lamp is easily managed; its fuel is stored in small space, and is readily available. Gas can only be employed where a supply exists, or can readily be made. Electricity requires machinery and skilled labour; it is, however, now passing beyond the experimental stage, and there seems little doubt, that where surrounding circumstances admit of its application, and where a specially powerful light is required, electricity will in future be called on to supply the want. There are now four stations on the English coasts lighted by electricity, and two others will soon be so lighted. Gas is used very largely for harbour lights, and there are some of the first-class lights in Ireland and Scotland where it is employed. All the remaining lights are oil lamps burning either vegetable or mineral oil. Many other sources of light have been experimented with in this and other countries, but they have all, from one cause or another, been found unsuited for lighthouse work. The most promising was the oxy-hydrogen, or lime-light. This, however, could not be made to give a perfectly steady light, and there was also the serious drawback that, even where coal-gas was available, it was necessary to store oxygen gas; while, where coal-gas could not be procured, it would be necessary to store hydrogen as well.

The oil lamp is formed with a series of concentric circular wicks, the number of which varies with the character of light required. In what was a few years ago termed the first order Trinity lamp, there were four wicks, the outermost of these being four-and-a-half inches in diameter. This was further increased by the addition of two more rings, bringing the whole up to a size of five inches across. These outer two are used only in foggy weather. Larger burners have also been constructed, the largest containing no less than ten rings. Thus is produced an immense mass of flame, giving a very brilliant light. It is argued by some that light proceeding from a large surface has greater penetrative power—can be seen farther through fog—than light radiated from a point. This opinion, however, seems more than questionable; it was put forward to account for the stated superiority in penetration of gas light, or light from oil, to the electric light. It is now more generally thought that if this superiority really exists, it is due to the composition of the lights themselves, not to the difference of size in their sources. Inasmuch as the focus of the optical apparatus is naturally a point, there are evident difficulties in adapting the lantern to a light from a large radiating surface, which do not exist when, as with the electric arc, the light is radiated from a very small surface. The best and whitest light is given by mineral oil, and the use of this is increasing. There are naturally varieties of construction in the various lamps, but for our present purpose there is no need to dwell upon these. Sometimes, as in lighthouses in India, or elsewhere, it is convenient to burn a local oil, such as cocoa-nut, &c., and the lamp is adapted accordingly.

The greatest success with gas seems to have been obtained with the burner invented by Mr. Wigham, and used by the Irish Board. In this a great number of gas jets—in the largest size as many as 108—are arranged in concentric rings. The flame from this lamp is larger than that from the large Trinity House oil lamp, and it is of course liable to the objection above-mentioned, in common with all large flames. There are, however, special advantages in the use of gas. The supply to each ring being separate, the size of the flame can be readily increased and diminished by cutting off or adding a ring, though this, too, is done with the large oil lamp. A flashing light can also be obtained without a revolving apparatus, by simply turning the gas off and on. Gas lamps on the Argand principle, resembling, in fact, the oil lamps above described, have also been tested, and with very satisfactory results.

The Trinity House have been actually using electricity since 1858. In that year, after some experiments carried on by Faraday and Holmes at Blackwall, a magneto-electric machine—a machine, that is, in which electricity is generated by revolving permanent magnets—constructed by Holmes, was set up experimentally at the South Foreland. The result of this trial, though it was held under unfavourable conditions, was considered satisfactory, and the light was permanently established four years later, in 1862, at Dungeness. Here the light had the advantage of an optical apparatus specially designed for it. Holmes's machines were still used, driven by steam-engines in the base of the tower. After some troublesome irregularities at first, the light burnt well and steadily for thirteen years. It was discontinued about 1875, because it was found that so powerful a light at a low level—the point is low, and the accretions to the beach since the tower was built have practically carried it inland, and thus reduced its apparent height—was inconvenient to ships navigating close in shore.

Encouraged by this success, lights on the same principle were set up at Souter Point (1871), at the South Foreland (1872), and at the Lizard (1878). The absence of water prevented a steam engine from being used to drive the machines at the Lizard, and consequently three hot-air engines were employed for this purpose. These engines are said to act satisfactorily without much attention, and to have proved themselves sufficiently well adapted for work under the peculiar conditions of a lighthouse. Each engine drives two machines. Sometimes one engine with one pair of machines is used, sometimes two, or sometimes one engine is used to work the fog signal and one to generate the electricity. In any event, the third engine is kept in reserve, ready to start at once in case of accident. Every arrangement has been made for shifting the current to either lamp, and a lamp is always kept in reserve, ready to be moved at once into place to take up the current, if anything goes wrong with the lamp at work.

All the above installations have worked satisfactorily, and the Trinity House authorities have it in contemplation to replace the machines at the first two stations named with others of a more powerful character.

The relative merits of the three systems of illumination have for long been anxiously discussed by lighthouse engineers, but the question may now be considered settled, at all events for the present, by the delicate and costly series of experiments carried on in 1884 and 1885, at the South Foreland, by a committee of the Trinity House. These trials were of the most exhaustive character, and they were also thoroughly practical, the various lights being tested in every imaginable way, and under the most varying conditions.

Three temporary wooden towers were erected, and each one was fitted up as a first-class lighthouse. One tower was devoted to electricity, one to oil, and one to gas. In each case the best and newest appliances were provided. For a period of over twelve months the experimental lights were regularly exhibited, and constantly observed. They were measured photometrically by trained experts; they were watched and reported on by a host of observers, trained and untrained, scientific and practical, sailors and landsmen. Long tracks were laid out with distances measured along them, at which the relative brightness of each light could be estimated by the eye, and the points noted at which each light grew dim, or disappeared in fog or mist. Their behaviour in all sorts of weather was carefully noted, and the result was that the committee obtained a very large amount of valuable evidence on which to base their report.

The result was distinctly favourable to electricity, as giving the most powerful light, while for convenience oil was considered superior to gas. The final conclusion of the committee was: "That for ordinary necessities of lighthouse illumination, mineral oil is the most suitable and economical illuminant, and that for salient headlands, important landfalls, and places where a very powerful light is required, electricity offers the greatest advantages."

It proved, as was expected, that a larger proportion of the electric light was absorbed by fog, than of the yellower light from gas or oil, but the initial power of the light was so much greater, the margin, so to speak, was so large, that this really did not matter. Electricity could afford to lose more, and yet came out victor in the end.

It was also found that the plan of superposing lights, placing two or three lamps, with suitable optical apparatus, one above the other, was effective in doubling or trebling the power, but that with the electric light no real advantage was found in doing this, as all the electromotive force available could conveniently be applied in a single lamp, with its single optical apparatus.

A PINCH OF SALT.

By William Durham, F.R.S.E.

THERE is no substance in daily use which is of more importance, or which will better repay a little attentive consideration, than common salt.

As an article of diet, it has been long known and appreciated. Without it, our daily food is insipid and tasteless, and perfect health, or even life itself, cannot long be enjoyed where it is absent. Its preservative qualities have been rendered famous in the symbolical language of moralists of all ages, and it formed an essential element in sacrifice. Ancient philosophers and poets have spoken or sung its praises, calling it "divine," "dear to the gods," and a "symbol of the soul.' To the present day it is, with the Arabs and the Slavs, the emblem of hospitality, and even with the most treacherous of the tribes the traveller is safe if he can once partake of their salt.

As we have said, it is essential to life, and it is also useful in promoting vegetation. Its health-giving qualities check the progress of many diseases, while in others—such as cholera—its deficiency in the blood is a significant fact. It is present in every part of the human frame—in the bone, in the muscles, and in the blood—and is widely spread through the whole kingdom of nature animate and inanimate.

It is not, however, with salt in its relations to life and vegetation that we propose to deal in this paper, but with some of its physical and chemical properties from which we shall learn that, even from this point of view, it well deserves the place of distinction it has so long enjoyed.*

Common salt has a considerable affinity for water, in which it freely dissolves, one hundred parts of water dissolving about thirty-five parts of salt. Curiously enough, cold water dissolves almost as much as warm water. This is an exception to the general rule. The attraction between water and salt produces some results which are sufficiently remarkable.

The following simple experiment will illustrate this. Take two glass jars, or two plain glass tumblers will do, and fill them with water; dissolve in one of them a few grains of common salt, and add to both some common white china-clay, stirring them well up, so that the clay is well diffused through the water, rendering it opaque. Care must be taken not to stir the one without the salt with the rod used to stir the one with salt. After stirring put both aside, and note how long the clay takes to settle in each jar, and the water becomes clear and transparent. A most remarkable difference will be noticed between the two. The water containing the salt in solution will be quite clear in about one or two hours, according to the quantity of salt dissolved, while the pure water will not be clear for twenty-four, or even thirty-six hours, if the water we use is very pure and soft. We see from this that the attraction of the salt for the water prevents the latter from holding the particles of clay in suspension. The results flowing from this action of salt on water are very striking and important. The waters of the ocean, as we all know, hold in solution a considerable quantity of salt; about three parts in a hundred is the average; in fact, it is like our tumbler or jar of water, to which we have added a few grains of salt, and consequently cannot retain in suspension for any length of time finely-divided matter—such as clay or sand. The obvious action of the salt, therefore, is to keep the ocean clear; all mud or silt is rapidly precipitated to the bottom, and forms those vast deposits found all over the bottom of the ocean in the dredging operations of the *Challenger*, and other vessels. Further, we know that the rivers of the world carry down to the sea immense quantities of worn-down rocks and soil. During flood we see our own comparatively puny rivers rendered quite brown and muddy from the amount of suspended matter which they carry along with them on their courses. Some of the more gigantic rivers of other countries are never clear, but are laden during the whole year with large quantities of this rock and soil waste, grinding down in the course of time the mountains and hills of the dry land, and carrying them into the midst of the sea. The waters of the Mississippi, for instance, are always muddy, and if we fill a jar from this river it will remain muddy and opaque for days. Now let us consider what happens when the mud-laden water reaches the sea. If we happen to live near the coast let us get a little sea-water and mix it with fresh water, in which we have stirred up a little clay, and note the result. The clay will be rapidly precipitated, and the water rendered clear. Now this is exactly what happens at the mouths of rivers—the mud and silt are at once precipitated where the river and sea waters meet. This is the reason why it is so difficult to keep the mouths of rivers and harbours clear of silt. We are compelled to use our dredging-machines continually, or they would rapidly be rendered dangerous to navigation.

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* The geological relations of the mineral have already been fully described in "Science for All," Vol. II., p. 279, so that it is here unnecessary to touch on any of its aspects discussed in that paper.

Many of us may have watched with interest the operation of building a railway embankment. We see the navvies lay down a plank as a stop at the place where they wish the wagon of soil to empty itself, and then, as it comes rushing along, strike up with a spade the bolt which retains the end of the wagon in its place; and so, when the sudden shock of its arrested progress tilts it up, the soil is precipitated where it is wanted, and thus the embankment is, bit by bit, built up to the required height. Now this process is wonderfully like what happens at the mouth of rivers. The grains of salt dissolved in the ocean may be regarded as a host of little navvies waiting for the drops of water, each coming with its little load of soil. They put down the stop, strike up the bolt, and cause the soil to be deposited in the depths of the waters. Hour after hour, day and night, the process goes on: small, indeed, is each load, but their number is infinite. Year after year the embankment rises nearer and nearer to the surface, and farther and farther out to sea. Soon the land lifts itself out of the waters; plants spread their roots and bind the slimy mass together; the currents of ocean and the winds of heaven carry towards it seeds from other lands; bushes and trees spring up, and animals find shelter in their shady retreats; man, the mighty hunter, follows, and it may be in time, fields of corn wave where erewhile stormy waters rolled, or towns and harbours and ships tell of the busy hand of civilised man, and a new continent is formed to take the place of those worn down by the tear and wear of nature's ceaseless toil. Thus we see that in the busy workshop of nature the humble condiment of our dinner-table plays no unimportant part.

Nor does the work of our little navvies end here, for it appears probable that they aid in returning the empty wagons or drops of water to the mountain tops, to renew their work of carrying it into the midst of the sea. Mr. Atkin, in a paper read before the Royal Society of Edinburgh, endeavoured to show that unless there were solid particles of matter floating in the atmosphere there would be neither fog, mist, nor rain, but that the surplus vapour would be at once deposited on all bodies on the surface of the earth. Our umbrellas would be useless, and our houses afford us no protection, as the rain would not fall from above, but merely appear like dew, but, unlike it, would find its way into every corner. Now, if this be so, and the experimental evidence brought forward by Mr. Atkin is very strong, it is extremely probable that particles of salt form a large proportion of this rain-precipitating matter. We can imagine this affinity for water attracting and condensing the particles of vapour until the drops become too large and heavy to remain suspended in the atmosphere, and consequently fall to the ground. We know, by the aid of the spectroscope, that salt particles are everywhere present—on the dust we brush from our coats or sweep from our rooms, as well as in that blown along our streets, or that dance in a sunbeam. Nor is this to be wondered at, as the ocean, the great storehouse of this substance, is ever hurling its spray into the atmosphere, or dashing its foam against the rocky barriers of our coasts, to be blown by the winds over the length and breadth of the land, and the salt it contains dried and scattered.

The attraction of salt for water produces many other phenomena of importance. Thus, for instance, the freezing of water is brought about by the mutual attraction of its particles, causing them to cohere in a crystalline form when the temperature is sufficiently lowered. Now, when salt particles are mixed with the water, they prevent, to some extent, this cohesion, so that the temperature must be further lowered according to the quantity of salt present before freezing commences. The result of this is, the sea does not so soon commence to freeze as it would do were its waters perfectly free from any saline ingredient. Thus in our temperate regions we are freed from the danger and discomfort of a frozen ocean similar to that of the Arctic regions.

Another result of this same property deserves to be mentioned. When salt is mixed with pounded snow or ice, the attraction of the salt causes the snow or ice particles to break up or melt, and the salt is dissolved. Now, when a solid becomes liquid, it absorbs a quantity of heat, and in the present case great cold is produced; sometimes the mixture indicates as low a temperature as 35° Fahr. below freezing.

It is sometimes customary in our large towns to utilise this property of salt in melting snow off the streets. This it does effectually, but when we consider the cold that is thereby produced, we see how dangerous a practice it is. Well-to-do people, with good thick boots, may not be seriously harmed, but to the poor and badly shod, the chilling effect of the mixture is fraught with no little danger.

Having examined some of the more prominent physical properties of salt as a whole, we shall now proceed to consider its chemical nature or composition, which, we shall find, is no less interesting and instructive.

When a chemist proceeds to examine any body, one of his first questions is, whether the substance is a simple elementary body or a compound; can it be broken up into two or more different kinds of matter, or does it always remain the same? A very simple experiment will show that salt is not elementary. All the apparatus needed is a Florence flask, a perforated cork, a piece of glass tubing, and a glass bottle fitted up, as in the annexed Fig. 1. Into the flask let us put a table-spoonful of salt and some vitriol or sulphuric acid, and apply a little heat cautiously by means of a lamp or gas flame. We shall soon perceive that there is some chemical action going on, as vapour will begin to condense in the bottle. On examining this condensed vapour, we shall find that it possesses acid properties, but that it is not the same acid as we put into the salt. It is a well-known substance called "spirits of salt," from its mode of production. Now, putting aside for further examination the residue of the salt and vitriol, let us take the spirits of salt and put it into a flask, and subject it, in the same apparatus, to similar treatment as the salt; but instead of vitriol let us mix with it a substance called black oxide of manganese, and heat as before. Instead of an acid coming off we shall get a gas of a yellowish-green colour, with a most penetrating and suffocating odour, and very dense as compared with air. Great care must be taken not to inhale any of this gas, as its effects are most painful. The writer has suffered severely for many hours from inhaling it, and only got some relief by breathing ether.

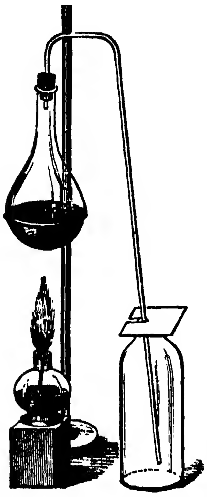
Fig. 1. — Experiment showing that Common Salt is not an Element.

This gas has been named chlorine from the Greek word for green, and is of much importance in many ways. It has never yet been broken up into anything else, and therefore is considered an elementary body, although there are some reasons for believing that it is a compound. Its properties are somewhat remarkable.

We generally suppose that when any substance burns it must be in an atmosphere of air or oxygen; but the behaviour of chlorine shows us that this is not at all necessary, and that burning is neither more nor less than chemical combination proceeding in a very energetic manner. If we introduce into a jar of chlorine gas a piece of phosphorus, the latter takes fire spontaneously and burns brilliantly; or if we throw in some powdered antimony, the combustion becomes evident by the shower of brilliant sparks. One distinguishing characteristic of chlorine is its intense affinity for hydrogen gas, and its indifference to carbon and oxygen gas. If we mix equal volumes of chlorine and hydrogen they will not combine in the dark, but if exposed to sunlight, or if a lighted taper be applied to the mixture, they will unite with violent explosion, like the well-known mixture of hydrogen and oxygen.

If a lighted taper be introduced into a jar of chlorine it will burn with a very smoky flame, because the chlorine combines with the hydrogen of the taper, and rejects the carbon which is deposited as soot. A very pretty and instructive experiment, illustrating the selection of the hydrogen and rejection of the carbon, may be performed by introducing into the gas a thin piece of paper soaked in spirits of turpentine. The turpentine bursts into flame, and the jar becomes covered internally with a copious deposit of carbon.

The most striking and useful property of chlorine, however, which indeed arises in great measure from its affinity for hydrogen, is its power of bleaching. It destroys vegetable colours most completely. This may be shown very readily by the following experiment. Take a piece of coloured cloth—say turkey-red—and draw some device or pattern on it with ordinary paste or gum, to which a little sulphuric acid or vitriol has been added. The cloth must then be dried and immersed in a hot solution of bleaching powder, which is a compound of lime and chlorine. The acid of the paste liberates the chlorine from the lime; the chlorine then bleaches the cloth wherever the paste has been put, and the result is a white device on a red ground. This bleaching property of chlorine is largely made use of in various arts and manufactures—such as linen and calico-printing and paper-making. The advantage of its employment is immense; processes which formerly took weeks or even months to complete are now readily finished in a few hours; fabrics, such as paper, which sixty or seventy years ago were more grey than white, now rival the snow in purity of colour. Thus beauty and utility are spread far and wide by the use of this ingredient of common salt. Another valuable property of chlorine is its disinfecting power; it rapidly destroys animal effluvia and offensive odours. It is, therefore, exceedingly useful in sick chambers and in deodorising drains, and for washing places where infection may be supposed to lurk.

During the cattle-plague some years ago it was extensively used in disinfecting cattle-trucks, byres, and other places where cattle had been, and thus prevented the farther spread of the disease.

Having thus shortly examined one of the constituents of common salt, we now proceed to study the residue left when the salt has been acted upon by vitriol or sulphuric acid, and the spirits of salt, or hydrochloric acid as it is more usually called, expelled. This residue is composed of a well-known substance called sulphate of soda, or Glauber's salt, and formerly much used as a laxative medicine. It is chiefly valuable, however, as the basis of one of the most extensive industries of the United Kingdom. When mixed with coal or charcoal and lime, and subjected to a process of roasting in a highly-heated furnace, it gives rise to a valuable substance known as soda ash, or carbonate of soda, which is of essential service in many of the arts—such as the manufacture of soap and glass, bleaching and dyeing, paper-making, and some metallurgical processes. It is produced in thousands of tons yearly, and gives employment to multitudes. Formerly this substance was produced from the ashes of a plant which grows luxuriantly on the coasts of Spain, and in some other maritime places. The production from this source, however, was limited, and it was only when the process of extracting it from salt was invented that the trade developed into its present enormous dimensions. Thus it is that the discoveries of science add beauty to the productions of art, and open up new sources of human industry.

Soda ash or carbonate of soda may be decomposed by boiling it with lime, when we get what is called caustic soda, a white waxy-looking substance with strongly marked alkaline properties, and more useful for many purposes than the carbonate itself. For many years this soda could not be resolved into anything simpler than itself, and it was reserved for the brilliant chemical genius of Sir Humphry Davy to show its compound nature. He brought to his aid that wonderful agent electricity, and by skilful manipulation separated soda into two bodies, one a metal, which he named sodium, and the other the well-known body, oxygen gas. It is easy to prove that the metal is the only substance besides chlorine which is really got from the common salt; the others, such as oxygen, carbonic acid, &c., being derived from the substances used to effect the analysis. The method of obtaining sodium employed by Sir Humphry Davy, though interesting and instructive, is not suited for general use, and it is now obtained by mixing carbonate of soda and powdered charcoal, and exposing this to intense heat in an iron bottle; the metal is vaporised, and passes into a vessel filled with naphtha or rock oil where it is condensed. Sodium thus obtained is a silver-white metal, though scarcely so brilliant in colour as that metal. At ordinary temperatures it is solid, but soft and ductile like wax, and easily melted. It is somewhat lighter than water, on the surface of which it consequently floats. Its distinguishing characteristic, however, is its intense affinity for oxygen. It rapidly combines with that gas when exposed to the air, and has therefore to be preserved in naphtha. A very pretty experiment may be performed, showing at once this affinity and the composition of water. A glass jar is filled with water and inverted, and a little bit of sodium carefully dried and wrapt in filtering or blotting paper quickly introduced under the edge of the jar. Being lighter than water it at once rises inside the jar, decomposing the water by combining with the oxygen and liberating the hydrogen, which collects in the upper part of the jar, and may be examined by the well-known tests for that gas. Great care must be exercised, however, in performing this experiment, as the action is often so rapid and energetic as to shiver the glass to the danger of the experimenter; sometimes when sodium is thrown on water the heat of combination is so intense as to cause combustion, and we see the somewhat novel spectacle of water burning, so that the proverbially difficult task of "setting the Thames on fire" may be easily performed with the aid of this curious metal. This affinity of sodium for oxygen is its most valuable property, so far as utility is concerned, and renders it of almost as great importance in the arts as soda itself. In metallurgical operations it is utilised in the production of aluminium, magnesium, &c. Sodium is interesting also as having supplied the key-note, so to speak, of spectrum analysis, which has so much enlarged our knowledge of the structure of the universe. When it is burned, or when common salt is thrown on the flame of a spirit lamp, the flame is coloured of an orange-yellow tint. When we look at this through a spectroscope we see a bright orange line at the commencement of the yellow colour in the spectrum, as in D, Fig. 2.

Now if we pass a ray of intense light from an electric lamp through the sodium flame, we see, instead of this orange yellow line, a black line which coincides exactly with a dark line in the spectrum of the sun's light. Reasoning on this phenomenon it was evident that it was due to the principle, that every substance in a state of vapour absorbs the same rays which it gives out. This conclusion was amply confirmed by observations on other substances, such as iron, &c., and the secret of the dark lines in the solar spectrum was thus unveiled; proving, at the same time, that this essential element of common salt, which is so abundantly present on the earth, is also present in the atmosphere of the sun, and thus it has acted as a guide leading us to a true knowledge of the elements which make up our wonderful solar system, and extending the boundaries of science into the remotest regions of space, wherever a star twinkles or a nebula sends forth its pale uncertain light.

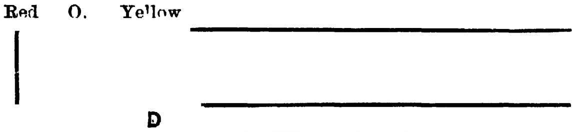

Fig. 2.—The Spectrum of Sodium.

We have shown that common salt is not a simple body, but is made up of at least two very distinct substances—one a dense yellowish green gas with an intensely suffocating odour, and possessing many remarkable properties; and the other a silvery white metal with such an intense affinity for oxygen gas, that it cannot be kept pure in the open air, and can even set on fire water itself: and these two when held together by the wonderful bond of chemical affinity, form the white comparatively inactive body, which gives savour to our daily food. Thus the common and cheap condiment of our dinner-table contains within itself a world of wonders. It keeps our bodies in health, and the ocean clean and pure; it helps to build up our continents, and to water the surface of the earth with refreshing and invigorating showers; it prevents decay and drives away disease; split up into its constituent elements it provides work for thousands; it cleans and beautifies our fabrics of fine linen and cotton; it gives us our snow-white paper, and provides soap for cleansing, and glass for beautifying, and thus enters into every department of human life like a good angel, carrying cleanliness, health, and wealth, wherever it goes.

ELEPHANTS.

By A. Leith Adams, F.R.S., F.G.S.,

Late Professor of Natural History in the Queen's College, Cork.

THE elephant, whose old world aspect is familiar to nearly every one, may fairly claim to be one of the most remarkably constructed, as it is the most ponderous of living land animals. The huge body, pillar-like limbs, short neck, enormous skull, projecting tusks, and long dependent upper lip and nose, or what is called the trunk, make up one of the most remarkable exteriors in the animal kingdom. As the clumsy and to all appearances awkward monster shuffles noiselessly past you on his great circular-shaped feet—twice the girth of which nearly equals the height at the fore-shoulder—you wonder how he can manage to get along. Notwithstanding, a good stepping elephant can compete with a sharp-trotting horse, and will straddle over many an obstacle the latter would hesitate to cross. In mounting precipitous places, the weight of the fore-quarters is thrown on the elbows; then cautiously one hind-foot after the other is moved up to the same level, followed by a supreme effort, and the huge animal is once more on all-fours. But the posture is awkward, so grasping the nearest tree or solid projection with the powerful trunk, he steadies himself for a minute before resting his elbows again at a higher level, and repeating the movements. Nor less novel is his method of descending, curling the snake-like trunk under his chin like the coiled-up proboscis of a butterfly, he rests the weight of the heavy head on this tough but pliant pad, as he slides down the incline on his belly and knees, with the fore-feet advanced for the purpose of breaking the force of his descent. The elephant swims with ease, and crosses broad rivers and estuaries, and but for a disposition to dive would be a safe and sure means of water transport. In point of intelligence a great deal might be said; suffice it, that ready obedience is the mainspring on which his usefulness in the domestic state is centred. His education depends a good deal on the requirements of the individual. For ordinary work three months' tuition is generally sufficient, whilst the most proficient are educated in a year after capture. It has been asserted that the Asiatic is far more docile and intelligent than the African elephant, but this is certainly not invariably the case, inasmuch as the two magnificent individuals of the latter in the gardens of the Zoological Society of London are quite as apt and intelligent, and are more active than the generality of the former.

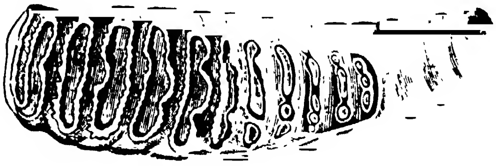

Fig. 1.—Molar Tooth of the Asiatic Elephant.

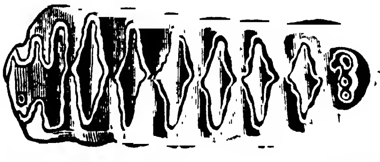

Fig. 2.—Molar Tooth of the African Elephant.

The two species differ widely in outward appearance. The African is the taller, and may be easily recognised by broader ears, less arching of the back, and more symmetrical proportions. The grinding teeth also differ, as shown in Figs. 1 and 2, and are admirably adapted for the particular sort of food on which each species subsists. The denizen of Asia feeds chiefly on tough grass and shrubs requiring a rough triturating surface; consequently the enamel of the crown of the molar (Fig. 1) is highly plaited, whilst in the other species which browses on leaves that do not require much chewing, we find the grinding surface (Fig. 2) is smooth; indeed, to the scientific eye every detail in the organisations of these remarkable creatures shows adaptability in accordance with the necessities of their lives. The enormous skull is needed to give thorough support to the ponderous tusks of solid ivory, and its great jaws for the enormous grinders, each of which may be a foot in length, whilst vacant spaces not required are hollow so as not to add to the weight. The neck is extremely short and well-adapted for the support of the heavy head, but would necessitate the animal going down on its knees when grazing, were it not for the pendulous trunk, appropriately designated a fifth limb. By means of this most useful organ—nothing more than an enormously developed nose and upper lip—it breathes, and can use it as a gigantic syringe and shrill-sounding trumpet, or turn it into a powerful organ of prehension and a delicate instrument of touch. So exquisite and effective, so pliant and lithe, that by means of this muscular apparatus it can pick up a needle, pull down a stately tree, and douche itself with water. When swimming across a river the only part visible is merely the tip of the trunk, by which it breathes. During the heat of summer, when fatigued, or annoyed by insects, the trunk, armed with a bundle of grass or a leafy bough, may be seen flicking flies, and fanning the flanks or brisket. Now tearing down branches and stripping them of their leaves, or coiling the organ snake-like around a clump of grass, it pulls up the mass, and beating the roots on its fore-legs to get rid of the sand, consigns the bundle to its mighty millstone grinders. The elephant, like the generality of animals which suckle their young, has two sets of teeth, viz., milk or

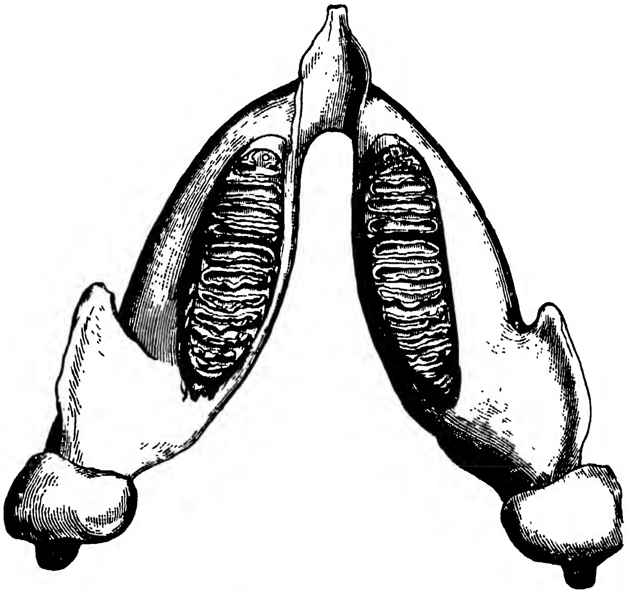

Fig 3.—Growth of Teeth in the Elephant.

deciduous, and true or permanent teeth. It has only two front or cutting teeth (incisors), called tusks, which are made up entirely of dentine or ivory and confined to the upper jaw, but instead of growing downwards they proceed outwards and form powerful weapons for attack or defence; moreover, African travellers state they are also used for uprooting trees. All the chewing is performed by the enormous grinders, of which there are no less than twenty-four, but never more than eight can be in use at the same time owing to the following peculiarity in their modes of replacement. Instead of getting a new tooth from below, upwards, the successor is formed behind the one in wear, and as the latter gets worn away in front, the other pushes it forward and gradually takes its place (Fig. 3), consequently the elephant may be said to be in a constant state of teething from birth to old age. At birth the calf weighs about 180 pounds, and is about two feet ten inches in height: it is then sparsely clad with hair, which however gradually disappears with age. The first or deciduous tusks are not much larger or thicker than the barrel of a goose-quill, and the first grinding teeth are rather less than an inch in length. These are succeeded by others, but in the case of the tusk, the new one is permanent, and increases in length and breadth by additions proceeding from the root; on the other hand the second grinder gradually displaces the first, and is as regularly removed by its successor, and so on until six relays of grinders are worn down, in all twenty-four.

Here again is a beautiful example of adaptation of means to ends. Had the replacement of the teeth of the elephant been from below upwards, the new grinder rising up would have displaced its predecessor before the former had time to fill up the large gap, whilst by the method adopted there is no void, for no sooner is the fore-part ground away than the pressure of the succeeding tooth behind pushes forward the remaining portion, so that (as seen in the lower jaw, Fig. 3) the surface in wear embraces part of the front grinder and portion of the next in succession. Considering, therefore, the material of which the grinders are composed, and their method of replacement, we may well believe that the animal might attain to a very great age.

As regards bulk and stature the largest instances occur among the African varieties, individuals of which attain a height at the shoulder of twelve feet, whereas the Asiatic rarely exceeds ten and a half, and the usual instances vary from eight to nine feet. It is needless to point out the advantages of a naked skin to such denizens of the tropics as the elephant and rhinoceros, or the thick pile of the bear and other animals of cold countries; but, as will be pointed out presently, both hairy elephants and rhinoceroses existed in the British Islands and elsewhere when climatic conditions necessitated a warm covering.

The Asiatic elephant is spread over the forests and jungles of North-western India to Assam. In the forests of the latter region no less than 503 elephants were captured during the three years ending with 1880 by the officials of the Indian Government. It also abounds in the provinces of Silhet, Chittagong, Tipperah, Cuttack, Pegu, Siam, and the Tenasserim Provinces, and likewise in Cochin China, and the Islands of Borneo, Sumatra, and Ceylon. Little is known of its previous history and distribution, but there is much probability that it extended westwards to Asia Minor, seeing that the skeleton of an elephant, apparently closely allied, if not identical, was discovered in the clay and sand of a river in the province of Erzeroum some thirty years ago.

Turning to the African elephant, the distribution of which has been much curtailed since Europeans commenced to settle on the continent, it was at one time plentiful as far south as the Cape of Good Hope, and had a much wider northern and lateral range than at present; it is, however, still plentiful in many parts of Central Africa, in spite of the great demand for ivory. Little is known regarding its distribution before the discovery of the Cape of Good Hope, but among the sand and material of an ancient sea-beach opposite Gibraltar, and also in several parts of Sicily and Western Europe, teeth of elephants have been found very much like the grinders of the living denizens of Africa. Moreover, associated with them in many instances are portions of the skeletons of hippopotami, lions, and hyenas, scarcely distinguishable except in dimensions from the bones of similar animals now inhabiting Africa. Supposing, therefore, that the living elephant, river horse, lion, and spotted hyena are the lineal descendants of these ancient forms, one is justified in concluding, first, that either the climate of Europe was much milder in those times, or else the survivors of these animals have gradually become habituated to the temperature of Central Africa. In the second place, the finding of the remains in the islands of the Mediterranean and throughout western Europe as far as England, seems to show, at all events, that there was direct land communication between the two continents, viz., between the British Islands and the Continent on the one hand, and the latter and Africa on the other. These and further evidences of great changes in the physical features of Europe and North Africa being among the established facts of recent scientific researches, are therefore quite admissible in attempts to trace the early history of the animals that still survive.

Such are the main features relating to the characters and distributions of the two living elephants which, but for the labours of the palæontologist, would appear to us as they did to our forefathers less than two centuries ago, to be the sole representatives, either in the past or present, of the remarkable order of animals to which they belong. The discoveries, therefore, of the last hundred years, and more especially within the last fifty years, show that they are the remnants of an extensive group of elephantine quadrupeds, which were spread over the Old and New Worlds in what geologists consider comparatively recent periods as compared with the animal relics from still older deposits. The majority of extinct elephants were generally much larger than any individuals of the Asiatic or African elephant. The reverse, however, obtained in certain cases which will be brought to the notice of the reader presently.

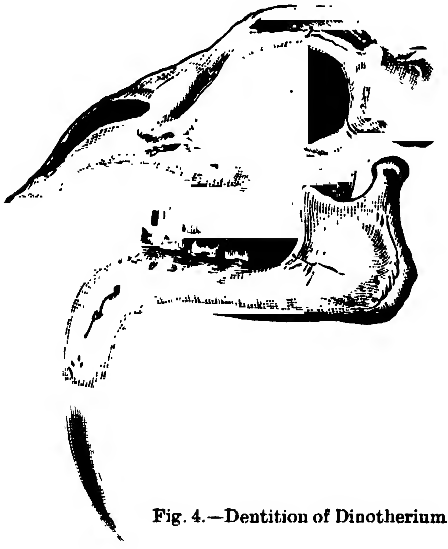

Fig. 4.—Dentition of Dinotherium.

The remains of elephantine animals have been found in various rock strata and soils; from the Miocene up to the Drift Period.* These when compared with each other, and with the frameworks of the living elephants, admit of being divided into three well-marked groups which, arranged in the order they are met with in the earth's strata, are 1, the Dinotherium—"terrible beast,"—so called from the remarkable size and shape of its tusks

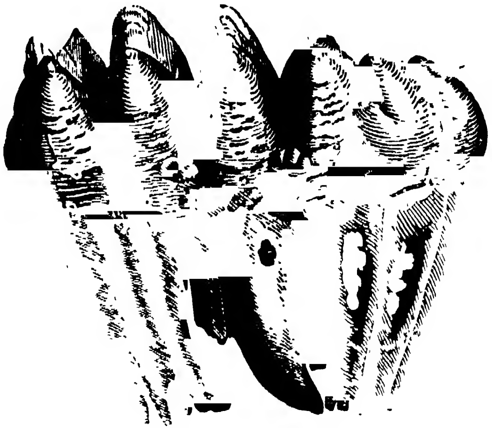

Fig. 5.—Molar Teeth of Mastodon.

(Fig. 4); 2, the Mastodons, from their grinding-teeth (Fig. 5), presenting the aspect of a series of teats or nipples; and 3, the true Elephants as represented by forms whose teeth have a general resemblance to those of the two living species (Figs. 8, 9, 10, 11). Belonging to these three types no less than twenty-nine to thirty-one forms or species have been described, exclusive of the recent denizens of Asia and Africa.

The earliest known members, or dinotherians (Figs. 4, 6), were of colossal dimensions, as shown by their bones; the skull measuring four, and thigh-bone five feet three inches in length. As just stated, these monsters were characterised by their formidable tusks which were placed in the lower instead of the upper jaw, like huge pickaxes directed downwards and backwards. Their remains have been discovered in various European countries and in India. But the most plentiful of all the Miocene or early forms were the nipple-toothed or mastodontine elephants (Fig. 7). These huge animals likewise exceeded greatly the dimensions of any living elephants. Many species were pretty generally distributed over Europe, Asia, and America; in the latter continent, entire skeletons have been found buried in the swamps of Ohio, Kentucky, and elsewhere. A noble specimen from Ohio occupies the greater part of a gallery in the British Museum; the length of this skeleton is seventeen feet, and each tusk is twelve feet in length. So well preserved are the remains in some cases, that although all the flesh had decayed, there

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* "Science for All," Vol. I., Frontispiece; and Vol. I., pp. 289, 291.

remained quantities of the characteristic leaves of pine and spruce trees in and around the position where the stomach would have been situated, thereby giving some clue to the nature of the food on which the lost animal subsisted. These entire skeletons turning up so frequently in swamps and marshes, might indicate that the individuals had been buried, just as elephants now are whelmed at the sources of the Nile, or as was frequently the case. so it is surmised, with the great Irish elk in bygone times.* As far as yet known, as many as from ten to thirteen sorts or species of these mastodons have been identified. Their remains have been dug up on the pampas of South America, in the swamps of the northern portion of the continent; on the southern slopes of the Himalayas; between Burmah and the Khyber Pass; and in southern and western India; in Germany, Switzerland, Malta, Italy, France, and England. In

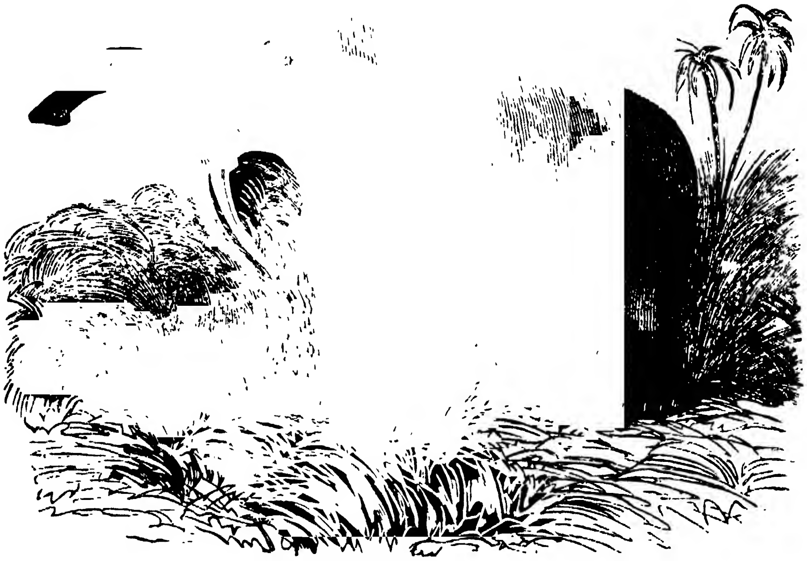

Fig. 6.—DINOTHERIUM (*Restored*).

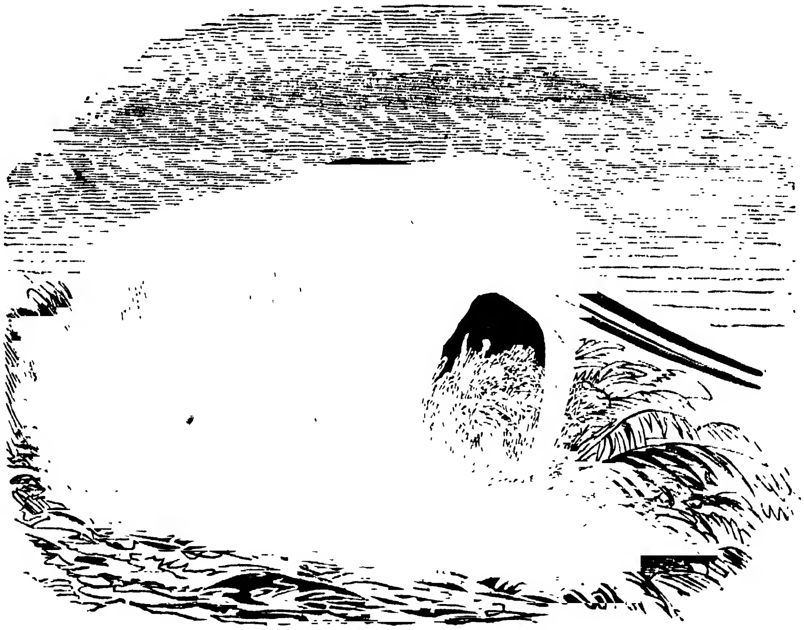

Fig. 7.—MASTODON (*Restored*).

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* "Science for All," Vol. I., p. 290.

outward appearance these nipple-toothed elephants resemble the living species; but besides two curving tusks in their upper, there were certain kinds that had long straight ones in the lower jaw.

The Indian elephant is the sole representative and survivor of some six or seven different members of its order which at one time roamed over Hindostan and the Western Himalayas—these elephants were in some instances accompanied by the mastodon—and, according to geologists, has been referred to both Middle Tertiary (Miocene) and more recent (Pliocene) periods. All along the southern flanks of the great Asiatic Alps, forming the northern boundary of British India, and even in their interior, also in the river sands and gravels of the central and southern portions of the continent, abundant remains of these huge monsters have been dug up in quantities, and often so well-preserved that there is no difficulty in distinguishing the individual characters of each kind.* Besides the elephants, there were found associated with them a nearly complete record of other large animals which sojourned at the same time on that ancient land surface and its waters. It is, moreover, interesting to observe that although several of these quadrupeds, birds, and reptiles, have died out, and were distinct from those now living, either in India and elsewhere, still, as in the case of the elephant, they have likewise their survivals; for example, the rhinoceros, still living in the swamps of northern India, was represented in those times by two or three different kinds. The hippopotamus not now found out of Africa was plentiful, four or five species having then existed; also the camelopard, and ostrich both now confined to Africa, were associated with the above. Add to the list lions, tigers, hyenas, more or less different in size and character from the living species, together with camels, deer, antelopes, oxen, sheep, and other strange and lost forms. Conspicuous among them was a monstrously large animal, combining the trunk of the elephant with the general characters of the camel, and other ruminating mammals. To this remarkable creature the name Sivatherium has been given. Another of these companions of the elephant was a prodigious tortoise whose shell measured twelve feet in length.

In this assemblage of animal relics it is apparent that there is a strange mingling of forms now living either in India or elsewhere with certain others which have completely died out. The elephants, with one or two exceptions, must have differed as widely from the present denizen of India as they did from one another. Thus the nipple-shaped tooth (Fig. 5) or mastodon elephant becomes in another form more like that of the living species, and it in turn passes directly into the latter, making a scarcely broken pedigree for the Asiatic and African elephants back to the mastodontine form. But these are only isolated links of the broken chain which lies hidden in the soils of the world, so that the future natural historian has every prospect of adding to our present knowledge of the ancestry of the elephant. Another remarkable link in its genealogy is presented by the dwarf elephants found some years ago in the soils of the little island of Malta. Until this discovery was made, all the evidence furnished by the extinct and living elephants showed that their order was characterised in the past as well as the present by the gigantic proportions of its members. At first it seemed uncertain that the remains did not represent young individuals, but a further investigation made it clear that vast numbers of a pigmy form of elephant, about the size of a donkey, had sojourned on a land of which the Maltese Islands are mere remnants. This was proved by the discoveries of quantities of teeth and bones, representing every stage of growth, from the calf to the aged. Some of the bones of the latter, as compared with the same parts of the living elephants, gave a height of about 3 feet at the shoulder, whilst others varied from 4½ feet to 6½ feet, the tallest being much below the smallest full-grown individuals of the two living forms. A tooth of one of these elephants is shown in Fig. 8. Hitherto these dwarfs have not been found elsewhere, but one of their companions has been identified in Sicily and Crete, viz., a hippopotamus of smaller size than the present river-horse of the Upper Nile. Besides the hippopotamus, enormous quantities of bones of a gigantic dormouse as large as a guinea-pig, and of huge tortoises as big as the present denizens of the Galapagos Islands have been found.

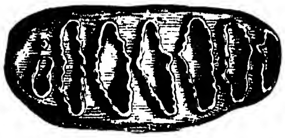

Fig. 8.—Molar Tooth of Pigmy Elephant.

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* Through the munificence and enlightened appreciation of science on the part of the late East India Company, there is scarcely a large public museum in England or on the Continent that is not in possession of specimens or casts of these remarkable relics.

Turning now to the continent of Europe in general, and the British Islands in particular, we find that herds of elephants inhabited England, southern Scotland, and Ireland. This is proved by the vast quantities of their remains found buried in caverns or in the soils, and river sands and gravels, more especially in the valley of the Thames. Their bones and teeth have also been dredged up in abundance by fishermen, on the east coast and along the floor of the German Ocean. Many of the relics found in caverns show signs of having been gnawed by lions, hyenas, and bears, as further proved by the finding of these animals' bones in the same situation, so that England must have presented much the appearance of the central Africa of our time, in the days when these mammals roamed over its plains and forests. The oldest traces of the true elephants hitherto discovered in Great Britain, refer to the Pliocene Period, and to an epoch before the famous Ice Age, as demonstrated by the discoveries of their bones in soils underneath the deposits formed by the glaciers and icebergs. For example, between the Wash and the Naze, along the coast-lines of Norfolk and Suffolk, there exists a submerged forest, discernible during unusually low tides. In the soil of this forest the old stumps of fir, spruce, and other trees, have been seen standing where they grew; whilst its deeper parts contain bones and teeth of elephants, rhinoceroses, hippopotami, and many other mammals.

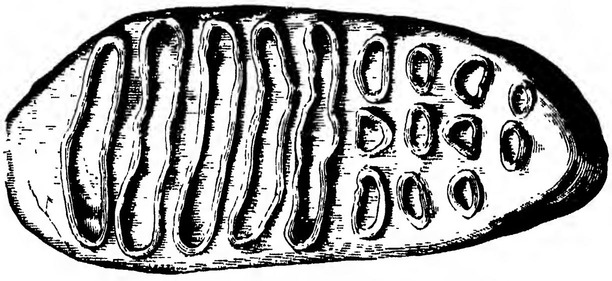
Fig. 9.—Molar Tooth of Southern Elephant.

The elephants are of three kinds :—

1. One sort, distinguishable by its teeth and bones, was of colossal dimensions; it has been named the southern elephant, because its remains were first discovered in Italy. The crown surface of one of its grinders is shown in Fig. 9.

2. Another elephant, rather smaller than the last, but often of ponderous size as compared with the two living forms, has been recognised as the ancient elephant, in consequence of its relics having been at first considered the more ancient. The tooth of this form is shown in Fig. 10, and it may be observed that there is a close relationship between certain teeth and bones of the ancient and African elephants, indeed some of the former are barely distinguishable from grinders of the latter.

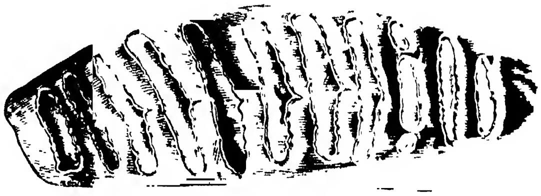
Fig. 10.—Molar Tooth of Ancient Elephant.

3. The last British elephant was the famous mammoth, whose tooth is shown in Fig. 11.

Now all the above have left their remains in the sands and clays of this old British forest, since submerged under the sea, and at one time probably, portion of a land area that united England with the continent of Europe, seeing that these elephants and the other associated mammals have likewise been found in abundance under similar conditions on the opposite coast of Holland, and in many countries inland.

Such are the general relationships and first indication of elephants in our islands, prior to the Ice Age or Glacial Period. The phenomena relating to this remarkable era in the earth's history need not be entered upon here, as they have been already described.* Suffice it to say, that the change of temperature was accompanied by momentous changes of level, in north-western Europe, whereby the British area was submerged to its highest mountain tops and re-elevated, when the emerged land assumed much the same contour as previously, and the climate became once more temperate. At this period many of the animals previously repelled to central and southern Europe gradually redistributed themselves over our country, and the mammoth and ancient elephants returned, but not the southern form, which apparently died out; at all events if it did survive, few, if any,

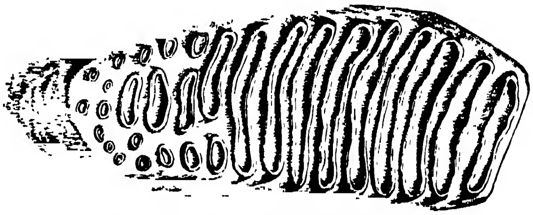
Fig. 11.—Molar Tooth of Mammoth.

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* "A Highland Glen:" "Science for All," Vol. I., p. 39.

came back to British forests. This is proved by the absence of its remains in soils deposited since the Glacial Period.

The mammoth or hairy elephant (Fig. 12), to which reference has been made elsewhere, and its geographical distribution in Europe, Asia, and America detailed,* seems to have been very plentiful in central and south-eastern England, and less so in Scotland and Ireland, where no traces of the ancient and southern elephants have hitherto been found.

The mammoth was the most cosmopolitan of all elephants living or extinct. It roamed over central and northern Europe from Ireland to the Ural Mountains, and from the latter across northern Asia to Behring's Strait, and southwards to Canada and the United States. In the latter country it was contemporaneous with another species called the Columbian elephant, whose grinding teeth resemble the Asiatic elephant's. The discoveries of carcases of the mammoth in the frozen soils of Siberia, and covered with long hair and thick masses of under wool, showed its adaptability to withstand cold climates, just as we find in the bears of the Far North and in tigers which extended beyond the Southern regions which are most familiarly known as their haunts. Like the ancient elephant and the African, there is also much in common between the mammoth and Asiatic elephant, so that it may be that the two living are the modified descendants of these extinct forms. Be that as it may, were it not for the discoveries of the extinct forms of these remarkable animals, very little could have been even surmised regarding the ancestry of the living elephants. This, however, is certain, that however much the species may have differed from one another, all have been built on one fundamental type of structure, which has been modified in various ways for the advantage of each form, as we have seen in the case of the grinding teeth of the two living species. The facts, however, are in too crude a state at present to admit of definite conclusions being drawn in relation to the evolution of the living and extinct elephants, but as man continues to displace the surface soils and deeper strata of the earth's crust, fresh discoveries will doubtless enable the natural historian of the future to see "face to face" what "we now see through a glass darkly."

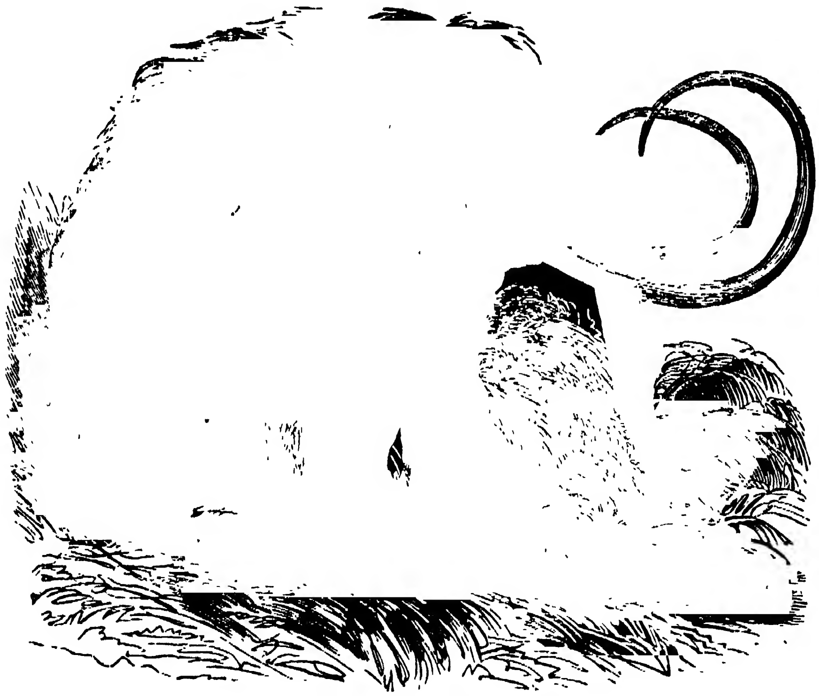

Fig. 12.—THE MAMMOTH (*Restored*).

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* "The Irish Elk, and its English Contemporaries:" "Science for All," Vol. I., pp. 134, 289.

CRACKS IN THE EARTH'S CRUST.

By Charles Callaway, M.A., D.Sc., F.G.S.

MOST old things tend to crack. The bark of an ancient tree is scored with countless crevices; many mediæval monuments in our churchyards are starred like a broken pane of glass; even the granite columns of ancient Egypt and the massive structures of the Druids crack and shiver at the touch of time. But, stranger than all, the solid globe itself is cracked and starred all over. Its crust is split into millions of fragments, varying in size from a few square yards to many square miles. The cracks which bound these pieces sometimes run for scores or hundreds of miles in a comparatively straight line, sometimes they are but a few yards in length. The crust of the earth is, in fact, like a tesselated pavement, made up of countless pieces, which yet fit so closely as to present the appearance of a continuous surface.

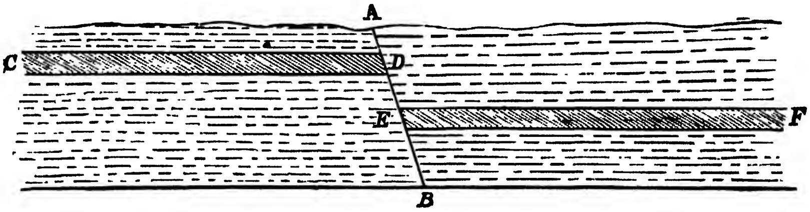

Fig. 1.- Fault Hading to the Downthrow.

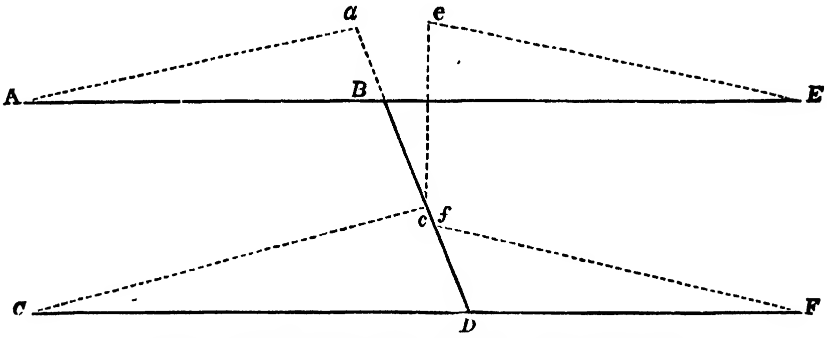

Fig. 2.—Showing Why Faults Hade to the Downthrow.

It is not difficult to understand why the globe should be cracked all over its surface. We must bear in mind that it was once a molten mass, and that during a long lapse of ages it has been gradually cooling down. When the melted matter at the surface had cooled down to a certain point, it solidified; just as a hard film forms on the surface of cooling gravy. As the earth lost heat, the crust grew thicker and thicker, so that now it is probably scores of miles in thickness. The globe is, then, a rigid shell enclosing a fluid and intensely heated mass. But the loss of heat is accompanied by contraction. The earth grows smaller as it grows older; as the interior shrinks, the crust, being spherical, is compelled to pack itself into a smaller compass. Thus powerful forces, acting laterally, will be set in motion: the solid shell will be puckered into waves, and the curvatures, being more or less rigid, will frequently be broken. The contraction of the interior will sometimes leave cavities into which portions of the overlying crust, being thus deprived of support, will fall. Cracks in the earth's crust are thus seen to be fractures caused by contraction due to loss of heat.

Sometimes these cracks are mere fissures which have not produced any displacement of the rocks on each side, but more frequently the fracture is accompanied by upheaval or depression, when it is called a *fault*.

The vertical displacement of a set of beds by a fault is called its *throw*, a fault being an *upthrow* or a *downthrow* according to the side from which we view it. In Fig. 1, A B is a fault, and C D E F is a stratum, say of coal, which is higher on the left side. We may not be able to say whether C D has been raised or E F lowered, but, in any case, C D is on the upthrow side of the fault and E F on the downthrow. The inclination of a fault is known to miners as its *hade.* In the figure, the fault *hades to the downthrow*, which is the usual rule. Under very exceptional circumstances faults hade to the upthrow, and are then said to be *reversed.*

Why faults usually hade to the downthrow will be evident from the following explanation and the diagram on p. 375 (Fig. 2). Let a section of the earth's crust, A C E F, be acted upon by a force which upheaves it in the middle, and splits it, causing the fault B D; then it is much more likely that the mass A B C D should be raised than the mass B E D F. For in the first place, A B C D has a wider base, and as it grows smaller towards the surface, it has a proportionately less mass to uplift than B E D F, which grows larger upwards. Then it will be seen from the figure that if B E D F were upheaved to (say) *e* E *f* F, an open gap would be formed along the line of fault, and the projecting mass (*e*) would overhang. No such difficulty would arise were A B C D raised to A *a* C *c*.

The same law is further illustrated by what are called *trough* faults. We must suppose that faults extend downwards for miles, for we cannot conceive that a portion of the crust should be raised or depressed at the surface without the underlying rock being similarly affected. If then a fault hade towards, say, the west, it will, at a greater or less depth, sometimes intersect a fault hading to the east. These two faults, forming the two sides of a great letter V, and called trough faults, enclose between them a triangular mass of the crust It is not difficult to imagine how these faults are formed, and why they hade to the downthrow. Let A B C D (Fig. 3) represent a section of the earth's crust. It is acted upon by an upheaving force which causes a fracture, which at first extends upwards from F as a single crack to G, where it bifurcates into a pair of faults G H and G I, forming a trough enclosing the triangular mass M. By a continuance of the upheaval, the fissure F G will open, forming a triangular cavity, into which the mass M will sink to a greater or less depth. The middle of the bed E E is thus thrown down towards G G, and the two faults H G and I G hade towards the downthrow. By friction and crushing, the angles at G G might be removed, and the wedge M might fill in the lower part of the triangular gap.

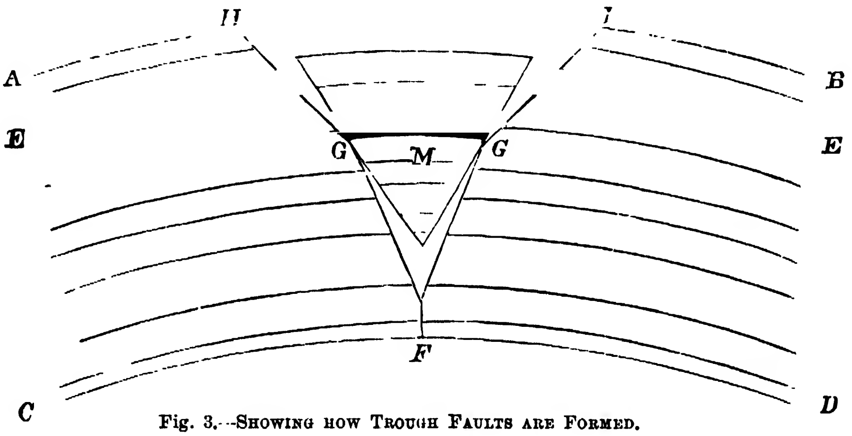

Fig. 3.—Showing how Trough Faults are Formed.

Recent investigation has brought to light many curious examples of the *upthrust* of wedge-shaped masses of the crust between a pair of faults. Underlying the great succession of fossiliferous deposits are certain ancient* rock-groups, called Archæan or pre-Cambrian. Their immense antiquity has exposed them during a long series of ages to the forces which fracture and rend the crust. They are consequently so broken and disturbed that it is a work of immense difficulty to make out their mutual relations. The island of Anglesey is a wonderful example of dislocation. It is a pavement of fragments of formations of different ages, thrown together in most confusing disorder Numerous wedges of rock, of from half-a-mile to several miles in length, are let down amongst older strata just as new tiles are let into a tesselated floor. The Malvern † range is a long wedge of Laurentian gneiss forced up between two faults; it is not a mass of molten matter which has risen up into a great fissure, but a fragment of the rigid crust, separated from the primæval floor of the globe by two parallel cracks, and thrust up through the overlying Cambrian and Silurian deposits which once covered it in. So great was the force of upheaval that it not only tilted up the strata on its flanks, but at some points it pushed them right over, so that the older overlie the younger. The Wrekin (Fig. 4), the classic Shropshire mountain, is a similar example. This ridge, which trends for nearly four miles in a straight line from north-east to south-west, is composed of bedded volcanic ashes and lavas of Archæan Age. The figure is a section across the axis. The Archæan rocks (1) appear to dip slightly to the north-west, their true dip being to the north. This triangular mass has been cut out of the ancient Archæan crust by two parallel faults, and subsequently thrust up through the beds 2, 3, 4, which originally overlay. To compare great things with small, it is as if a piece of the first floor of a house were cut out, and forced up through the second and third storeys, tilting up their joists and boards on each side in its upward progress. The faults which cut out this rock-wedge run in a straight line to the south-west, through Shropshire into Radnorshire, and here and there similar fragments of the old earth-floor are pushed up between the cracks, and form hill ranges. We must bear in mind in all these cases that at the time of their original upthrust, these fragments were probably covered in by thousands of feet of strata; that the superincumbent masses have since been removed by denudation; and that the wedges themselves have undergone considerable reduction in size and modification of shape.

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* "Science for All," Vol. III., p. 204 † *Ibid.*

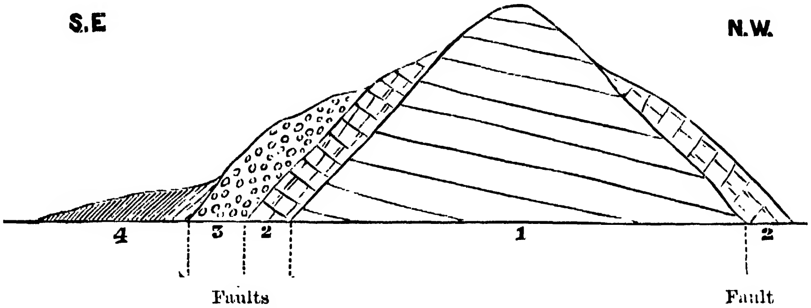
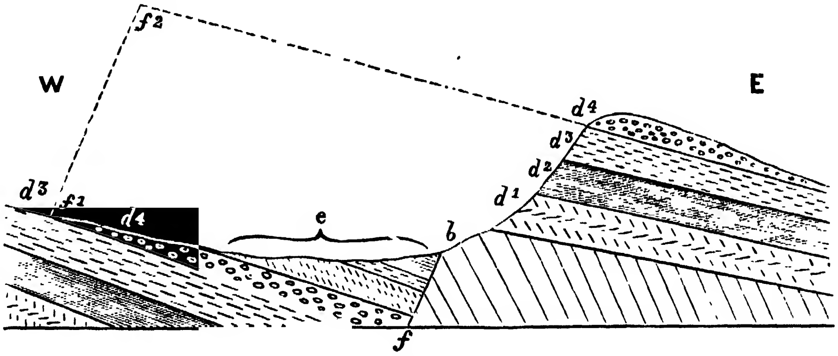


Fig. 4.—Section Across the Wrekin.



. 5.—The Pennine Fault.

Faults often bring together rocks of different ages. In Fig. 1 it is obvious that the beds above E F are newer than the band C D, which was originally continuous with E F. In this case the beds brought together are merely higher and lower bands of the same formation, but frequently rock-groups which are thrown to the same level differ in age by many millions of years. An excellent example of this is shown in Fig. 5. The elevation to the right is the Pennine range of Cumberland and Westmoreland. Its cliff-like "escarpment," facing the west, overlooks the valley of the Eden. This escarpment is composed of Carboniferous rocks (*d*) resting on the upturned edges of Lower Silurian slates (*b*). Thrown down against these old rocks by the fault (*f*), are sandstones of Permian Age (*e*), a formation still newer than the Carboniferous, which crops out at the surface farther to the west. If we prolong one of the beds in the escarpment (say d^4) to the west by means of the dotted line, it will be seen that the fault has thrown down the Carboniferous and Permian rocks to the distance f^1, f^2.

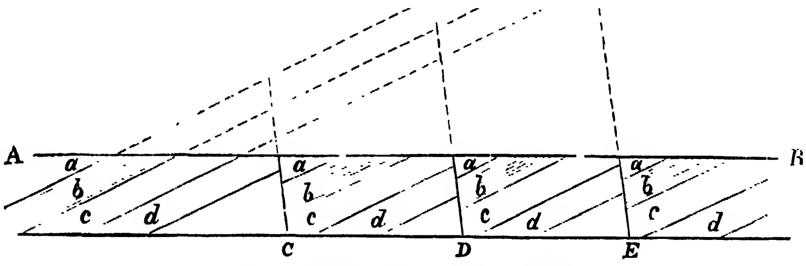


FIG. 6.—REPETITION OF BEDS BY FAULTS.

A succession of faults may cause frequent repetitions of the same strata. In Fig. 6 the beds *a*, *b*, *c*, *d*, are thrice repeated by the faults, C, D, E, so that in passing from A to B the same band (say *a* or *b*) is seen four times. The original position of the strata is represented by the dotted lines. If we did not recognise the faults, we might suppose there was a continuous ascending series from B to A. The importance of these observations is seen in mining operations. Let *b* be a coal seam. A surveyor who did not detect the faults would suppose there were four distinct beds of coal, and the property would be valued at four times its real worth. But the fallacy would be evident on working, for as the miner excavated the bands to the right of the fault C, he would come down to the faults C, D, E, and would find sandstone or shale instead of coal. This is an illustration of the money value of scientific knowledge. Speculators are sometimes ruined by the representations of so-called "practical men," who affect to despise the teachings of true science. It has been estimated that the cost of the Geological Survey of the United Kingdom might have been defrayed out of the sums wasted in ignorant explorations for coal.

It may naturally be inquired, How can we find out faults? We do not see the cracks which you say traverse the surface in all directions: how is their presence indicated? To this it may be in part replied that sometimes we do see them. We rarely detect the actual crack or fissure on the horizontal surface of the ground owing to the drift or soil which usually covers the bare rock; but in sea-cliffs, in mountain scarps, even in quarries and railway-cuttings, the fracture may often be observed. Sir Roderick Murchison and Prof. Geikie describe a wonderful example of faulting in the Torridon district, in the North-west Highlands. Red sandstone and white quartz-rock are thrown down against each other in alternate strips cut out by faults, the dislocating force sometimes wedging in the younger formation below the older. The red and white bands are repeated again and again, and as they are clearly exposed along the side of a glen, they "give the declivity all the appearance of a vast diagram." Usually, however, the existence of faults is a matter of inference. One kind of proof is the following. If we know that a certain, bed B, is normally found below another bed, A; and then find at any spot that B is in such a position in relation to A, that by no possible contortion or inversion could it be brought to pass below it, then there must be a fault between them. Examine the section in Fig. 6. We find at the surface of the ground above D and E that the bed *a* is in contact with the bed *c*. We know by examining unbroken districts that the true position of *a* is above *c*, with *b* intervening. It is, therefore, obviously impossible that *a* should pass under *c*, and the necessary inference is that between *a* and *c* there is a fault which has brought down *a* to the level of *c*, or forced up *c* to the level of *a*. Or take the actual example shown in Fig. 5. The Permian sandstones (*e*) dip as if they would pass below the Carboniferous beds (*d*). But the true place of the Carboniferous is below the Permian. As it is obvious that the Carboniferous rocks in the escarpment could not by any possibility be got to pass beneath the beds (*e*), which lie so far below them in the valley, a fault is inferred at the foot of the scarp. The presence of still older rocks (*b*) under the Carboniferous (*d*) would serve to strengthen the proof, were that necessary; but in some parts of the valley the slates (*b*) are absent, and the Permian is faulted directly against the Carboniferous.

The fault just described is of great length, extending from Scotland into Yorkshire. Commencing in Dumfriesshire, it is continued in a south-south-east direction, passing up the valley of the Eden as the Pennine Fault as far as Brough. It then turns to the south-south-west, running by Kirkby Stephen and Dent to Kirkby Lonsdale and Ingleton, where two branches, called the Craven faults, are given off to the east. The course of this well-known system of faults is shown in Fig. 7.

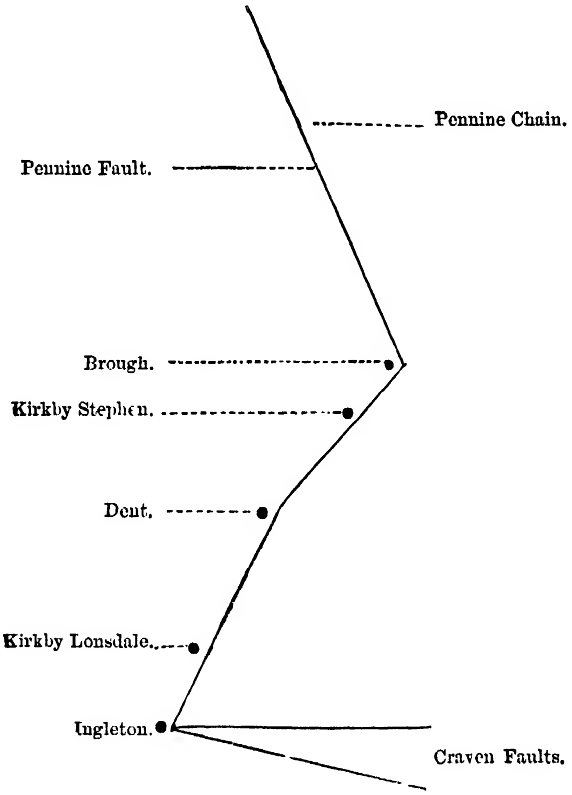


Fig. 7.—Diagram of the Course of the Pennine Fault.

It is estimated that, in some parts of its course, the Pennine fault throws down the strata as much as 6,000 or 7,000 feet.

As the earth's crust is so sadly dislocated and shattered, it might be expected that its surface would be very irregular, the upheaved fragments forming mountains, and the depressed areas constituting the intervening valleys. Strange to say, however, the mountains are usually created, not by the stupendous fire-forces which rend the solid crust asunder, but by the gentle and unobtrusive agency of running water.[*] If the inequalities originally made by faults remained, the earth's surface would be an uninhabitable chaos of tremendous precipices and appalling crevasses. Scenery would consist of cubic or pyramidal blocks of rock, with angular gulfs between. But the action of frost and waves, eating away the more prominent masses as they emerged from the ocean, has gradually planed off the inequalities. The island of Anglesey is, perhaps, the most faulted district in Britain, yet it is almost a level plane; and the few insignificant elevations which stud its surface are due, not to dislocation, but to the unequal hardness of the rocks. Faults which threw down strata thousands of feet have left not the slightest inequality in the surface. The stupendous masses of rock which once rose on the upthrow side have been clean swept away. It is almost as if a carpenter were to fit together a number of blocks of wood, many of which should rise higher than the rest, while their degrees of hardness should vary. Then let him cement them into a solid mass, and plane off all the irregularities, producing a level surface. Lastly, let him rub this surface with sand-paper so thoroughly as to wear away the wood to a depth of, say, a quarter of an inch in the softest blocks, leaving the hard blocks standing up higher. Then the lines of separation will represent faults, and the hard blocks, which will have been rounded off by the sand-paper, will answer for mountains. Knots in the wood of the softer blocks will also represent mountains.

Connemara, in western Galway, is another illustration of the subordinate influence of dislocations upon scenery. This charmingly picturesque district is a wild sea of mountains, of which the Twelve Pins (or Bens) of Binabola are the culminating crests. The rocks of Connemara are chiefly granite, gneiss, mica-schist, limestone, serpentine, and quartz-rock, with numerous intrusive dykes and masses of felstone and diorite. On examining the coloured map of the Geological Survey, we observe that each kind of rock has a distinctive tint, so as to be easily recognised. We also notice that the map is scored by countless white lines, as if the demons popularly supposed to have originated most noted mountains, had celebrated the completion of their tasks by a dinner, and left all the gridirons scattered about. These lines represent faults. Their prevailing direction is from north to south. But the scenery has not been materially affected by these cracks and dislocations, numerous as they are. The map shows us that all the important elevations are in the patches which are coloured yellow, which indicate the bands and masses of quartz-rock. The durability of this variety accounts for its prominence. Quartz is but little affected by chemical forces, and it also yields but slowly to the disintegrating influences of frost and running water. The trend of these hills is, on the whole, from east to west, agreeing with the strike of the quartzite beds, and, of course, at right angles to the general run of the faults. Sometimes one of these ridges is crossed transversely by a dozen parallel faults within the breadth of a mile. The denuding forces, however, declining to permit competition on the part of the fire agencies, have removed such inequalities as the faults may have originally produced, and, scooping out the intervening bands of schist and limestone, have left the hard quartz-rock beds exposed as lofty mountain ridges.

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[*] "Science for All," Vol. I., p. 116.

The old rocks which form the magnificent scenery of the Scottish Highlands are likewise extensively dislocated by faults, but the varying hardness of the rock-masses is here also the chief cause of inequalities in the crust. Such fine peaks as Schiehallion and Ben More of Assynt are masses of quartzite isolated by the removal by denudation of the softer rocks surrounding.

But while faults in their influence upon scenery are subordinate to other causes, they have their share in the result. The valley of the Eden (Fig. 5) is not only due to the softer nature of the Permian sandstones as compared with the rocks of the Pennine chain, but to the depression of the crust to the west of the fault. Denudation in this case has not removed the beds on the upthrow side, though it has probably greatly reduced their elevation. The Malvern and Wrekin ranges also owe their existence in part to faults, but had it not been for the great durability of the upheaved wedges of rock, they must long since have been planed off to the general level. It happens in both cases that the flanking strata are much softer and more easily washed away. Faults often produce inequalities in the surface when they bring together rocks of different degrees of durability. The junction is a line of weakness along which the denuding forces act with effect. Hence faults frequently run along the bottom of valleys and lakes. Bala Lake, for example, lies in the line of a great dislocation which runs from Cheshire through part of Denbighshire, down through Bala Lake, and on to the sea near Towyn, a distance of nearly sixty-six miles. But on the whole, we may conclude that "the gentle rain from heaven" has more materially contributed to the production of the inequalities which give beauty and magnificence to "this round of green, this orb of flame," than the convulsions which have so extensively cracked and rent the crust of the globe.

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